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Corona Fatality Development and the Environment: Empirical Evidence for OECD Countries

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Abstract

This paper presents empirical results on coronavirus fatality rates from cross-country regressions for OECD countries. We include medical, environmental and policy variables in our analysis to explain the death rates when holding case rates constant. We find that the share of the aged population, obesity rates, and local air pollution levels have a positive effect on fatality rates across the different estimation equations. The strategy of aiming to achieve herd immunity has a significant positive effect on death rates. Other medical and policy variables discussed in the public sphere do not show a significant impact in our regressions. An evaluation of different health policy stringencies does not yield clear conclusions. Our results suggest that improving local air quality helps reduce the negative effects of a coronavirus pandemic significantly.

Key Words: Coronavirus Pandemic, Fatality Rates, Local Air Pollution, OECD Countries, Health Systems, Environmental Policy

JEL Classification: I10; Q53; I18;H12.

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1. Introduction

Negative pollution externalities are a key topic of environmental economic research. Diseases, particularly communicable diseases, are another important form of negative impact on both human well-being and the economy at large. They can cause great damage, especially when they occur on a large scale, such as the recent coronavirus pandemic of the disease known as COVID-19.[1] After its emergence in China in December 2019, the disease quickly spread around the whole world. Within a few months, governments around the globe have taken measures to combat the epidemic in their own countries – including temporary lockdowns of the population and shutdowns of certain production activities. The rapid spread of the virus in Western Europe and the US has presented an enormous test for acute care stations in hospitals where, in April and early May 2020, capacities were fully exhausted in some regions of Italy, France, Spain and the UK.[2] The novel coronavirus and the disease which it has caused was initially considered to be a "pneumonia of unknown etiology" and early research identified that the underlying virus was related to the coronavirus grouping, possibly related to SARS and MERS (SUN ET AL., 2020).[3] From this perspective, it is of particular interest to understand how existing respiratory problems in certain patients and the state of the environment in the form of air quality problems could possibly contribute to morbidity and mortality, respectively; this would establish a direct link between the external effects of pollution and pandemics. Other patient predispositions, such as obesity or diabetes, could also play a role. The subsequent empirical analysis takes into account many variables in an effort to explain fatality rates; herein the regressions with the most interesting results will be presented for OECD countries. This group of countries is of particular interest since many OECD countries were reaching a peak in infections and fatalities in a rather parallel fashion; but there is also the differentiation between those countries which aimed rather at achieving an early level of herd immunity – notably, Sweden, the UK and the Netherlands – and other countries which place more emphasis on quarantine measures and social distancing as well as other selective interventions with the aim of minimizing the diffusion of the coronavirus.

Besides the historical medical challenge, COVID-19 infections have created serious economic problems in more than 100 countries, in particular in OECD countries where the output decline in the first and second quarters of 2020 has reached double digits. Even if one would follow the scenario analysis of the BANK OF ENGLAND (2020) that the UK will have a 14 percent output decline in 2020, followed by a 15 percent increase of output in 2021, the Bank's warning that the United Kingdom might witness the worst recession in 300 years naturally is a cause for concern. The impressive growth which was

[1] In January 2020, the World Health Organization (WHO) declared that the COVID-19 outbreak met the criteria to be classified as a "Public Health Emergency of International Concern" (WHO, 2020a). On March 11, 2020, the WHO finally declared the international epidemic to be a pandemic, namely an epidemic which was now affecting countries in all regions of the world (WHO, 2020b).

[2] Some German hospitals could accommodate a relatively small number of COVID-19 patients from Italy and France in April 2020. While the anti-epidemic policy measures in OECD countries have helped to bring down infection rates and to flatten the infection and case fatality curves over time, the cumulated number of COVID-19 fatalities in some EU countries have been rather high – for example, in the UK, Italy and Spain - while Germany has recorded a rather low number of case fatalities.

[3] A specific problem concerns how COVID-19 case fatalities are classified where death cases in care homes presents a particular issue – the relative number of case fatalities seems to be relatively large as the elderly have higher death rates than the younger generation; in particular, the identification of a case of COVID-19 in a care home for the elderly in Belgium has the consequence all further death cases in that care home in spring and early summer 2020 were automatically classified as COVID-19 cases without further testing. Different coverage of testing across countries – including post-mortem testing – thus lead to different numbers of case fatalities.

witnessed in China over many years came to a halt in the first quarter of 2020 when Chinese authorities were coping with the COVID-19 challenge, which seems to have emerged early on in the province of Hubei at the end of 2019. In the US, the number of unemployed has increased by more than 40 million within only twelve weeks. For certain OECD countries, the enormous expected output declines, the steep rise of deficit-GDP ratios, and the strong increase of unemployment figures (IMF, 2020; European Commission, 2020) indicate an enormously negative side-effect of the coronavirus pandemic.[4] While the earlier SARS and MERS epidemics where primarily regional, from an international perspective, the coronavirus pandemic is truly global and a very serious medical, social, political and economic challenge for most countries. From an economic perspective, the coronavirus pandemic is in the first instance a global symmetric shock, however, different reactions of policymakers in various countries could create differing epidemic developments across countries. The IMF World Economic Outlook of April 2020 suggested that the world economy will face an almost global recession (IMF, 2020).[5]

The present paper provides empirical evidence on the effect of pollution on COVID-19 fatality rates in OECD countries. It relates to various strands of recent literature. An early publication on the economic and health care aspects of the coronavirus pandemic is WELFENS (2020a) who points to the role of health system quality, the age structure of the population and identifies theoretical aspects related to growth modelling and the structural breakdown of the economy.[6] HOLTEMÖLLER (2020) develops a medium-term economic model in which an epidemic model is combined with an economic business cycle model.[7] The relationship between health and the environment has been the subject of a specific literature. In an early contribution to the theory, GUTIERREZ (2008) uses an overlapping generations framework where pollution imposes health problems on households when they are elderly; pollution raises health costs inducing precautionary savings and capital accumulation so that the economy is more likely to be dynamically inefficient. In a similar setup, WANG ET AL. (2015) study precautionary savings, health insurance, and environmental policy as a response to health risks, which depend on environmental pollution; it is found that optimal environmental policies and the optimal health insurance environment are deeply intertwined. BRETSCHGER AND VINOGRADOVA (2017) develop a stochastic framework for an endogenously growing economy, which is subject to pollution-induced health shocks and where the health status is a component of the welfare function. The paper derives closed-form analytical solutions for the optimal abatement policy and the growth rate of consumption; it shows that devoting a constant fraction of output to emissions' abatement allows for achieving the first-best allocation in the economy. BRETSCHGER AND VINOGRADOVA (2019) generalize the

[4] It cannot be ruled out that after an initial phase of flattening the infection and death curves, there could be a second wave of infection and, in the future, a third wave of infection - until either a vaccine is available or herd immunity is achieved.

[5] The new pandemic is creating enormous challenges in OECD countries and the uncertainty in the early months of that pandemic makes determining adequate policy measures aimed at fighting the pandemic a difficult task: It seems that most OECD countries did not have adequate stocks of masks, disinfectants and medical personal protective equipment for the coronavirus pandemic, despite the fact that, e.g., all EU countries and Switzerland had an established official Pandemic Plan. Indeed, the pandemic quickly revealed weak points in many OECD countries.

[6] The contribution discusses the tradable and the non-tradable sectors and considers the role of international tourism as well as some growth modelling insights (with effective labor supply in the production function negatively affected by the share of uninsured population/workers with a weaker health status). Moreover, with respect to potential corona morbidity risk, the ratio of acute care beds relative to the population aged 65 and above is emphasized, as it seems that fatality rates are higher for the elderly.

[7] The model assumes that labor input in the production function is negatively influenced by infections and COVID-19 death cases, respectively - so that welfare analysis can be applied within a hybrid economic-epidemic approach.

concept of induced shocks to a broader class of models for endogenously growing economies and derive optimal policies to reduce the damage to households efficiently.

Turning to empirical studies, early data from case fatalities in China suggested that the elderly population experienced a higher mortality rate than the overall population (WANG ET AL., 2020). With respect to coronavirus-related deaths in the US, there is an early empirical analysis of case fatalities by medical researchers for US regions (WU ET AL., 2020). The authors consider a battery of medical and other variables to explain regional case fatalities in the United States.[8] SHERPA (2020) looks into the specific role of austerity policies on COVID-19 fatality rates and indeed finds significant evidence in the case of OECD countries for that variable. Sherpa's quantile regression analysis indicates that austerity measures in OECD countries (here, cuts to health expenditures) significantly increase the COVID-19 mortality rates in those countries.

As regards the structure of the respective underlying virus, SARS, MERS and COVID-19 are closely related. With respect to the link between pandemics and the state of the environment, CUI ET AL. (2003) report a positive association between air pollution and SARS case fatality rates in the Chinese population studying 5 regions with 100 or more SARS cases. EVANS AND SMITH (2005) examine whether serious health conditions are related to current and long-term exposure to particulate matter and ozone. The findings suggest significant current and long-term effects of air pollution exposure on new cases of heart attack, angina, chronic lung conditions, and shortness of breath. HE ET AL. (2016) study the exogenous variations in air quality during the 2008 Beijing Olympic Games and find that a 10 percent decrease in PM10 concentrations reduces the mortality rate by 8 percent. DERYUGINA ET AL. (2019) estimate the causal effects of acute fine particulate matter exposure on mortality, health care use, and medical costs among the US elderly using Medicare data. They use changes in local wind direction as an instrument and machine learning to estimate the life-years lost due to pollution exposure. The paper finds that mortality effects are concentrated in about 25 percent of the population of elderly residents. In a quantitative cohort study conducted between 2000 and 2018 in six US metropolitan regions, WANG ET AL. (2019) find that long-term exposure to ambient air pollutants is significantly associated with increasing health problems in particular emphysema and worsening lung function. Summarizing previous empirical findings, CONTICINI ET AL. (2020) conclude that individuals living in areas with high levels of air pollution are more prone to developing chronic respiratory conditions, which partly explains a higher prevalence and lethality of novel, highly contagious, viral pandemics such as COVID-19 in those regions.

Our paper builds on these contributions and tests the main empirical hypotheses with novel data for COVID-19 fatality rates in OECD countries. In the subsequent analysis, we first take a closer look at measurement aspects of case fatality rates in OECD countries and in a more general perspective (Section 2). Section 3 develops the basic hypothesis for the subsequent empirical models and describes the data series. In Section 4, we present the regression results. Section 5 concludes with the policy conclusions and perspectives for further research.

[8] It is noteworthy that an online, regional COVID-19 Simulator tool was quickly developed by two research groups (Harvard Medical School researchers based at Massachusetts General Hospital and researchers from the Georgia Institute of Technology) which allows an understanding of the impact of alternative regional policy strategies in terms of soft measures versus stricter regional lockdowns.

2. Corona Case Fatalities: Descriptive Statistics and Data Problems in an International Perspective

The basic idea based on the previous discussion and the literature, respectively, is to analyze the link between case fatality rates related to the novel coronavirus and a selection of exogenous variables which should include medical, demographic and environmental factors plus other data. As a first step, one has to consider the measurement of fatalities from COVID-19 where several varying sources and methodologies exist.

There are three different approaches to measuring fatalities from COVID-19 cases, namely (i) the Johns Hopkins University (JHU) approach covering different data sources (JHU, 2020), (ii) the WHO measurement approach based on the official governmental reports of the member countries, and (iii) the excess mortality estimates that indirectly attempt to measure COVID-19 deaths. For (ii) we have to note the differences in the measurement of COVID-19 deaths between different regions and institutions, even within individual countries. For (iii), excess mortality figures are available from EuroMOMO, which is a network covering 24 countries/regions in Europe.[9] One important policy perspective here could be to assess the need for international and intra-country (regional) political solidarity based on excess case fatalities if there are different international or regional classifications/coverage of COVID-19 fatalities.[10] The concept of excess fatalities, i.e. the difference between the actual numbers of deaths in a certain period compared to the number one could normally expect for the same period could be a useful measurement tool for covering COVID-19 fatalities in an international environment in which countries' COVID-19 fatalities statistics are not harmonized. There is, however, the problem of data availability and indeed a need that the OECD and the UN would provide harmonized excess mortality statistics.[11]

Additionally, national statistical coverage might be different at the beginning of the epidemic and in the later peak stage where for practical reasons the coverage could change; e.g., with acute care capacities in hospitals overwhelmed and a lack of sufficient testing kits available, the testing for COVID-19 patients who die at home or in care homes will be rather incomplete at that particular stage of the epidemic. If countries are all close to or immediately beyond peak fatality – with a logistical curve relevant for infections and case fatalities, respectively – no major problem with a comparative analysis of case fatalities should occur since countries' fatalities and case fatality rates are in the upper, flat, part of the logistical curve. In the EuroMOMO bulletin for week 18 (late April 2020), the authors note for the European countries covered: "The excess mortality estimated by the EuroMOMO over the past weeks appears to have peaked in all countries by now." (2020a, p.1). From this perspective, a regression

[9] In the EuroMOMO (2020a) Bulletin of week 18, 2020, key findings are summarized as follows: (i) "...overall excess mortality is driven by a very substantial excess mortality in some countries, while other countries have had no excess mortality. The mortality excess is primarily seen in the age group of >= 65 years, but also in the age group of 15-64 years" and (ii) the EuroMOMO (2020b) Bulletin of week 19 shows that England had the highest excess mortality in week 17, 2020, while Germany, for example – actually Berlin and Hesse as two possibly representative German states – showed no excess mortality in the whole first quarter of 2020. Germany officially had about 7000 Corona case fatalities by late April. This makes clear that replacing WHO data by excess mortality figures also can have its problems. The Italian statistical office (ISTAT, 2020) has calculated regional excess case fatalities which, unsurprisingly, show considerable variation across regions.

[10] The UK is an interesting case since the coverage in Scotland, for example, in March 2020 was broader than that in England and Wales.

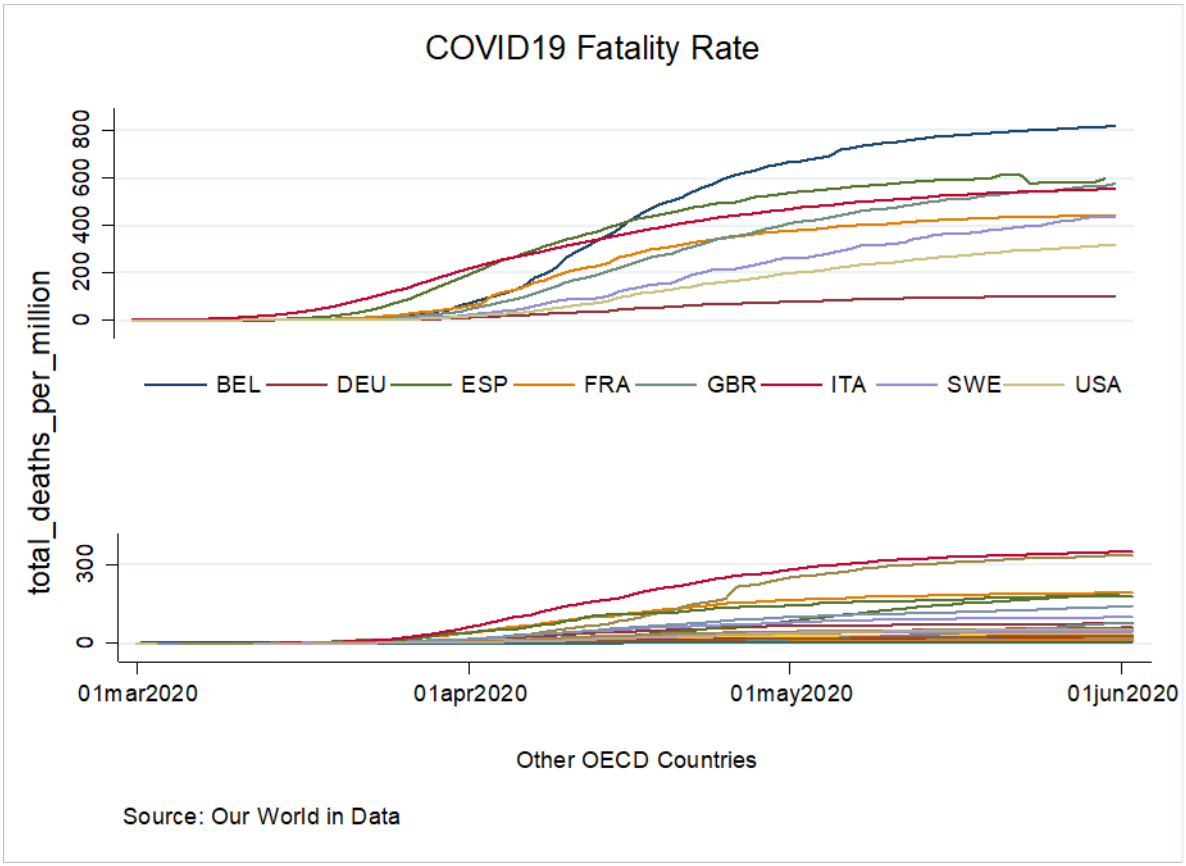
[11] Manski and Molinari (2020) highlight the absence of bounds on infection rates and explain the logical problem of bounding them; they find that the actual infection rates might be substantially higher than reported.

analysis of cumulated case fatalities in western and eastern European countries at the end of May should be adequate; one may also assume that the US peak in case fatality rates had been achieved in May 2020. To the best knowledge of the authors, no OECD country is still expecting a peak in case fatality rates in summer 2020.

As regards the number of infected persons, the WHO and the Johns Hopkins University coronavirus research group (DONG/DU/GARDNER, 2020) report slightly different numbers of COVID-19 case fatalities.[12] Differences are explained by the fact that the WHO relies on national governments' reported fatality numbers while the Johns Hopkins University also takes into consideration press reports on case fatalities (JHU, 2020). All reported data naturally contain a lag of about a week since testing and test result reporting as well as death reporting brings delays. Our subsequent analysis will, however, not look at the death rate of a single day – as reported by authorities, the WHO and the JHU, respectively; rather we are interested in explaining the cumulated case fatalities associated with COVID-19. To the extent that epidemics typically follow a logistical curve – with the number of patients recovering (R'; assumed to have immunity against the virus) being a barrier to the further spread of infections - there is a theoretical problem in comparing death rates across countries to the extent that the start of the respective national epidemics show large lags across countries. As regards lags in OECD countries, one may assume that the enormously dense flight and travel networks, respectively, will bring smaller time lags across countries. It should also be mentioned that as long as the absolute number of infections is small, the contact tracing of infected persons is obviously is relatively easy so that an early detection of the outbreak and massive tracing and quarantine measures could strongly bend down the infection curves – see, e.g., the Republic of Korea and Taiwan. In the OECD countries, only Iceland appears to be a country where early testing and government intervention seems to have brought a particularly favorable situation in terms of infection intensity (infections – as officially measured – relative to population). Fatality rates (measured by deaths per million of population (population figures for 2018)) differ considerably across the OECD countries, see Figure 1; in most OECD countries, the peak in terms of fatality rates had apparently been reached by the end of May, 2020.

[12] The definition of a COVID-19 fatality according to the WHO (2020c) is as follows: *"COVID-19 death is defined for surveillance purposes as a death resulting from a clinically compatible illness in a probable or confirmed COVID-19 case, unless there is a clear alternative cause of death that cannot be related to COVID disease (e.g. trauma). There should be no period of complete recovery between the illness and death."*

Figure 1: Fatality Rates in Selected OECD Countries (cumulated death cases until 2 June 2020, per million (population figures for 2018))



Source: Own representation

The results for OECD countries indicate considerable differences in fatalities. In the subsequent ranking of countries (see Table 1) one can see that on the basis of fatality rates at the beginning of June 2020, the top five countries were Belgium, Spain, the UK, Italy and France, followed by Sweden, the Netherlands, Ireland, the US and Canada. The five best performing countries were (in descending order) Japan, South Korea, Slovak Republic, New Zealand, and Australia. Among the big economies with a rather favorable record in Europe – and with high levels of international trade and tourism linkages, including with China – is Germany, ranked 14, whose fatality ratio was less than 1/3 of that of the US (a month before the ratio was ½). Three ranking places behind Germany are Denmark, Mexico and Austria; the latter's fatality ratio is only about 1/10 of that of Belgium (Tab. 1). Press reports (see, e.g., BEISEL, 2020) have argued that Belgium's death rate is particularly high since care homes with one COVID-19 fatality will record all subsequent mortality cases – without testing – as being linked to COVID-19. In any case, it is remarkable that countries show considerable differences in terms of fatality rates.

Table 1: COVID-19 Fatality rates in OECD countries (cumulated COVID-19 fatalities from January 1 to June 2, 2020, per million population (population figures for 2018))

Rank	Country	Fatalities per mn	Rank	Country	Fatalities per mn	Rank	Country	Fatalities per mn
1	Belgium	818.49	13	Portugal	139.65	25	Israel	33.16
2	Spain	597.59	14	Germany	101.71	26	Czech Republic	29.98
3	United Kingdom	575.16	15	Denmark	99.44	27	Iceland	29.30
4	Italy	553.66	16	Mexico	78.86	28	Poland	28.38
5	France	441.73	17	Austria	74.17	29	Lithuania	25.71
6	Sweden	435.97	18	Chile	58.22	30	Greece	16.79
7	Netherlands	347.95	19	Finland	57.75	31	Latvia	12.72
8	Ireland	334.16	20	Hungary	55.07	32	Japan	7.07
9	United States	317.66	21	Turkey	54.10	33	South Korea	5.31
10	Canada	194.11	22	Slovenia	51.95	34	Slovakia	5.13
11	Switzerland	191.34	23	Estonia	51.26	35	New Zealand	4.56
12	Luxembourg	175.73	24	Norway	43.53	36	Australia	4.04

Source: Own representation using data available from Our World in Data

Certain EU countries with very high fatality ratios have suffered at some point critical situations in terms of acute care capacities in hospitals as is witnessed by the relocation of COVID-19 hospital patients from Italy and France to Germany. Among the countries covered in the graph and the table above, Sweden, with its rather liberal epidemic policy – with limited lockdowns imposed on Swedish families early on – does not show a favorable performance in the field of COVID-19 fatalities; Sweden, the Netherlands and the UK are three countries which placed an early emphasis on herd immunity. One cannot easily argue that countries with high fatality rates have been strict in early lockdown measures and shutdowns, respectively. Among the countries with rather low fatality rates, Greece is remarkable as a country which imposed strict regulatory quarantine measures rather early on. A systemic approach requires a broad econometric analytical approach.

Based on our assessment of fatality and excess fatality rates in OECD countries, we choose to use COVID-19 death rates in the empirical part, holding the COVID-19 case rates constant. This reflects the heterogeneous standards of measurement in the different countries as well as the random spread of the pandemic between the countries. In principle, to have the infection rates instead of the case rates would be preferable but these figures are unfortunately biased and unreliable, unfortunately. It turns out that the most important predictor for the number of deaths is the number of cases. Hence, when attempting to estimate the impacts that health and environmental variables have on the number of deaths, we therefore include the number of cases in order to avoid omitted variable bias and improve the precision of our results.

3. Empirical Model and Data

Explaining epidemic case fatalities is a rather difficult challenge – certainly with a limited sample of data. Among the key variables to be considered are predispositions in the various OECD countries' populations and possibly influences relevant for the respiratory system. This potentially includes, for example, air quality aspects and thus crucial environmental aspects.

The choice of dependent variable is not straightforward. While one is typically interested in the infection fatality rate, i.e. the ratio of deaths to infections, this number is unreliable, especially in an ongoing pandemic. This is due to the difficulty in accurately estimating the number of infections in a cross-country perspective, as different countries have varying testing regimes. In this paper, we rather focus on the death rate per million, as there is less variation in how deaths from COVID-19 are tested and reported across countries. However, as different countries were affected to differing degrees by the virus due to a combination of luck and successful policies, the death rate per million is not necessarily informative on its own. To get around this issue, we include the reported number of cases by country in all our regressions, as keeping the number of cases constant allows for a more informative comparison of the factors that affect deaths per million. We are aware that even the measurement of cases involves some differences between countries, which leads us to interpret our results with caution.

Our main independent variable of interest is pollution, measured by mean exposure to PM2.5 in the largest city of each country. The rationale behind focusing on the largest city is that in most countries, the virus hit large cities the hardest, so most victims of the virus would be living in the largest city or in cities that are very similar in terms of air quality. This data is missing for Iceland, Israel, New Zealand, and Turkey, leaving us with a sample of 32 countries for the regressions including pollution. To control for other potential factors affecting the lungs, we also include the percentage of smokers in each country. A priori it is not clear what effect we should expect from this variable, as smoking has also been linked to lower case fatality of COVID-19.

More recent insights from corona fatalities show that fatality rates are higher for the elderly, and that COVID-19 attacks the blood circulation and related cells in addition to the respiratory system. Being overweight has also been suggested as a risk factor in COVID-19. The health condition of the population at large thus appears to be an important factor, and we thus control for the percentage share of the population aged 65 and above, as well as the percentage share of the population that is overweight in all our specifications.

Further, predisposition factors in the health system could play a role. There could be weak points in the availability of adequate personal protective equipment for medical personnel and indeed care personnel in nursing homes. OECD countries are a rather homogenous group of high per capita income countries, which one may expect to have relatively good health systems. However, it should not be overlooked that a few OECD countries do not have full health insurance coverage of the population; an important case here is the US where 13 percent of the population has no health insurance under the Trump Administration, 2 percentage points higher than under the Obama Administration. Such a lack of health insurance coverage could cause infected patients without insurance to delay going to the doctor or to the hospital until the disease has progressed. This reduces the probability of survival, since the health status of COVID-19 patients often deteriorates quickly to a critical stage. We therefore include the Global Health Security (GHS) index to control for the overall preparedness of the health system.

High fatality rates more or less force government to adopt strict shutdown and lockdown measures – effectively a stringent quarantine approach – since otherwise the intensive care capacities in hospitals would quickly be overwhelmed.[13] When successful, such measures reduce the transmission rates and the number of cases which, in turn, lowers the death rate per million. While most of the policy response would be captured in the number of cases, we also attempt to control for policy responses. Relying on the policy indices from the Oxford COVID-19 Government Response Tracker (OxCGRT), we calculate the mean value of the stringency index from 1 January to 1 June, 2020. The stringency index includes information on the level and generality of closures and containment measures of various governments, a detailed index methodology can be found in the working paper of HALE ET AL., (2020).

The intensity of OECD countries' tourism- and business-related contacts with China – in both directions - could play a role for infection rates, but not necessarily for case fatalities: Once there is a critical propagation of the virus in Europe, certain EU regions can themselves become significant sources for the spreading of the virus. As a proxy for international business linkages and travel, we include each country's openness in terms of FDI flows.

The variables are described in Table 2, with summary statistics in Table 3. A correlation matrix is included in the Appendix.

Table 2: Description of the Variables

Variables	***Description***	***Source***	***Expected sign***	***Time period***
Deaths per million	Total deaths attributed to COVID-19 per million people	Our World in Data (OWID)		31.12.2019-02.06.2020
Deaths per million (until May)	Total deaths attributed to COVID-19 per million people until 30.04.2020	OWID	+	31.12.2019-30.04.2020
Cases per million	Total confirmed cases of COVID-19 per million people	OWID	+	31.12.2019-02.06.2020
Percent above 65	Share of the population that is 65 + years	OWID	+	Latest year available
Percent overweight	Estimated share of the population that is overweight	WHO	+	2016
PM2.5 in largest city	Mean exposure to PM2.5 in the largest city	OECD	+	2017
Percent smokers	Average percentage of male and female smokers	OWID	+/-	Latest year available
GHS Index	Overall score of the Global Health Security Index (0-100, 100= highest score)	GHS Index 2019	_	2019

[13] This risk always exists once the so-called R infection factor exceeds unity (R indicates a critical parameter of the spreading function of the virus). With R>1, the system moves to an exponential virus diffusion function as one infected person will infect more than one other person so that it is only a question of time until hospital capacities are exceeded.

Herd immunity policy	A dummy variable equal to 1 if a country applies the herd immunity policy (UK, Sweden, and the Netherlands)	News items*	+	2020
Mean policy stringeny	Mean of Stringency Index (0-100, 100=strictest response)	OxCGRT	_	2020
FDI openness	Ratio of adjusted FDI inward and outward flows to GDP (own calculations)	OECD	+	2018

Notes: OWID uses the data from the European Centre for Disease Prevention and Control (ECDC), OxCGRT represents the Oxford Covid-19 Government Response Tracker.

*For the Netherlands, see the speech by Prime Minister Mark Rutte on March 16, 2020: https://www.government.nl/documents/speeches/2020/03/16/television-address-by-prime-minister-mark-rutte-of-the-netherlands;
for Sweden, see public comments from the country's chief epidemiologist Anders Tegnell https://www.svd.se/tegnell-flockimmunitet-inte-huvudtaktiken?fbclid=IwAR0ESWZX8S_QbSWcnSCKGaHxhnw_gBxTxn88CsHwoAWOMlCB7i1BhDTIPPI;
for the United Kingdom, comments from the United Kingdom's Chief Scientific Adviser Sir Patrick Vallance: https://www.ft.com/content/38a81588-6508-11ea-b3f3-fe4680ea68b5

Source: Own representation

Table 3: Summary Statistics

	N	Mean	SD	Min	Max
Deaths per million	36	167.11	209.70	4.04	818.49
Cases per million	36	2307.22	1877.24	133.23	6415.58
Percent above 65	36	17.45	4.00	6.86	27.049
Percent overweight	36	61.71	8.18	29.4	70.2
PM2.5 in largest city	32	13.59	5.63	5.8	25.3
Percent smokers	36	25.57	7.06	14.15	43.65
GHS Index	36	61.68	9.66	43.8	83.5
Herd immunity policy	36	.08	.28	0	1
Mean policy stringency	35	39.81	5.64	21.19	55.37
FDI openness	36	4.26	3.34	.19	16.38
Deaths per million (end April)	36	122.84	165.73	3.28	647.217
Cases per million (end April)	36	1767.41	1577.61	111.39	6020.99
Observations	36				

Source: Own representation

4. Empirical Results for OECD Countries

The results of our regression analyses are reported in Table 4 where a range of regression equations are considered.

The effect of the three baseline variables, total cases per million, the share of the population aged 65 and over and the share of overweight persons in the population, are reported in column 1. The number of cases per million is a consistently strong predictor of the number of deaths, which is not surprising. One more case is associated with between 0.07 and 0.09 more deaths in a country. A large elderly population is also important: A 1 percentage point increase in the number of people aged 65 or over is associated about 10 to 20 more deaths per million. The overweight variable is only significant in columns 2, 3 and 6, but has a positive sign as expected. A one percentage point increase in the share of overweight amongst the population is associated with about 5 more deaths per million.

In column 2 we introduce the pollution variable. The results indicate that an increase of 1 µg/m3 PM2.5 in the mean exposure to PM2.5 in the largest city is associated with an increase in deaths per million of slightly more than 10. However, while our results generally show that an increase in PM2.5 concentration appears to be associated with a higher number of deaths from COVID-19, the results are not highly robust. Further research on a larger sample is required before one can conclude that an increase in pollution causes a higher fatality rate from COVID-19. The effect of the percentage of the population in a country who smoke has a negative sign, indicating that smokers could have a lower fatality rate compared with non-smokers. However, the result is only significant in one specification.

The total score of a country in the GHS index appears to be a bad predictor for the number of deaths per million, as it is statistically insignificant and the sign on the coefficient is positive. The same regressions were also run with scores in the sub-indices of the GHS, which showed largely similar results and are thus omitted here. The herd policy variable appears important as it is statistically significant, and the coefficient is large. A country that initially pursued a policy of herd immunity appears to have around 175 more deaths per million than other countries.

In column 4 we introduce the mean policy stringency variable as a control, while dropping the herd immunity policy control. The policy stringency does not appear statistically significant. However, the stringency of policy could be quite endogenous to both the severity of the outbreak and the fatality rate: A harder hit country might introduce very strict regulations once the true nature of the threat has been acknowledged.

In column 5, we introduce the FDI openness variable to control for international business exchange. While the coefficient is positive as expected, the results are not statistically significant. The final column shows a robustness check: Running the regression in column 3 on the number of deaths until the end of April 2020. The results are not majorly affected by the different choice of data.

Table 4: Regressions Explaining COVID-19 Deaths per Million

VARIABLES	(1) Deaths per million	(2) Deaths per million	(3) Deaths per million	(4) Deaths per million	(5) Deaths per million	(6) Deaths per million (1 May)
Cases per million	0.0720***	0.0847***	0.0799***	0.0796***	0.0796***	0.0877***
	(0.0184)	(0.0200)	(0.0209)	(0.0194)	(0.0198)	(0.0204)
Percent above 65	16.77**	23.12***	20.42**	18.77**	20.44**	12.99***
	(7.062)	(7.452)	(7.517)	(7.254)	(7.742)	(4.293)
Percent overweight	3.606	5.486**	4.961***	3.541*	4.973***	3.761***
	(2.857)	(2.589)	(1.724)	(2.046)	(1.751)	(1.225)
PM2.5 in largest city		10.29***	11.29**	7.869	11.35**	12.11***
		(3.693)	(4.048)	(6.130)	(4.157)	(2.717)
Percent smokers		-7.114**	-4.351	-3.716	-4.333	-0.392
		(3.313)	(4.362)	(4.644)	(4.406)	(2.612)
GHS Index			2.952	5.125	3.044	4.635
			(3.571)	(3.370)	(3.447)	(3.126)
Herd immunity policy			139.5**		137.3*	92.24*
			(59.60)		(72.01)	(47.14)
Mean policy stringency				6.342		
				(7.684)		
FDI openness					0.663	
					(8.644)	
Constant	-514.2*	-718.5***	-911.8**	-1,138***	-921.9**	-936.1**
	(267.3)	(240.3)	(376.1)	(358.1)	(389.0)	(348.9)
Observations	36	32	32	31	32	32
R-squared	0.516	0.615	0.674	0.657	0.674	0.723

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Own representation

5. Policy Conclusions and Research Perspectives

The coronavirus pandemic raises key questions from a medical, economic and political perspective. If there is to be some international solidarity, the international community could decide to allocate particular help to those countries with a high number of fatalities per million. While the regression model looks at fatalities in OECD countries, the next steps in research will be to include more countries, if possible all UN countries; a necessary step for broad policy recommendations in the context of a global pandemic. The following reflections are thus only part of a broader analytical effort which in the end should not overlook critical links between medical and economic dynamics in an international pandemic. Countries with both high infection rates and high numbers of COVID-19 deaths have obviously suffered particularly negative shocks in production, namely to the extent that there was an infection-related decline of production, the effective labor input has reduced, or that strict regulatory shutdowns and lockdowns were imposed by government that were designed to fight the epidemic but brought the side effect of a negative supply and a negative (aggregate) demand shock. Given the simple fact that fatalities differ so much across OECD countries, one may argue that our regression findings cover at least a critical part of the analysis. There may also be special aspects in the medical perspective that we as economists would want to cover only in a more interdisciplinary research context; international differences in health systems and hospital quality thus could play a role which is only indirectly covered here, namely in the number of infections registered in the various countries. With these caveats in mind, one may focus on preliminary policy conclusions.

There is a range of key policy conclusions one could draw as it was shown that the COVID-19 fatality rates of OECD countries depend on the number of coronavirus infected people, the share of the population aged 65 and above, the share of overweight people in the population and the PM2.5 centration in the respective biggest city. The latter variable is a proxy for air quality problems which have increased over decades in the major cities of OECD countries, but we cannot be sure that this indeed is an adequate variable to represent negative predispositions of potential COVID-19 fatalities (further investigation in the future will be needed here for OECD countries, but one may also hope that more internationally comparative regional studies could be useful here; with a high number of regions to be considered, the degrees of freedom will be raised which should be useful for including more explanatory variables). An important conclusion from the findings presented herein is that countries with a strategy of achieving herd immunity early on is doubtful as it raises the case fatality ratio in a significant way; in a broader perspective this approach is less convincing the faster a vaccination against the coronavirus becomes available. While it is true that selective policy interventions – summarized in the mean policy stringency variable – is not significant in the regressions presented, it seems too early to discard the usefulness of such policy interventions which include social distancing and quarantine measures. There is likely an indirect effect in the form of a reduced number of cases of infection and this aspect, as well as questions of regional variations, could only be analyzed in further research. As regards the environmental air quality variable, one should emphasize two points here: (i) This variable should be carefully considered in order to anticipate particular regional/national epidemic hotspots in a future second infection wave. (ii) An emphasis on sustainability policies which bring down particulate matter intensities should be understood to be also part of strategic health care policy.

It is interesting to recall the British Government's information on PM2.5, namely as noted by the British Department for Environment, Food & Rural Affairs on its website (HM GOVERNMENT, 2020): "*Inhalation of particulate pollution can have adverse health impacts, and there is understood to be no*

safe threshold below which no adverse effects would be anticipated…The biggest impact of particulate air pollution on public health is understood to be from long-term exposure to PM2.5, which increases the age-specific mortality risk…". The government source continues to describe sources of PM2.5, in particular car traffic and industrial pollution, as well as heating processes; certain precursor gases also are relevant for the creation of PM2.5. In the future, assuming that our regression findings can be extended in a robust way for more UN countries – or a larger number of regions of the world economy - one would have to add the role of PM2.5 for coronavirus pandemic fatality rates. One may expect that a switch from fossil fuels to renewable energy and climate change policy will considerably reduce PM2.5 air quality problems. According to the analysis presented herein, climate change policy would also reduce current and future fatality rates from COVID-19 and similar epidemics/pandemics so that there is an additional argument for promoting renewable energy and certain environmental innovations. The finding that obesity is a variable which is significantly raising case fatalities suggests that countries and regions, respectively, which have a relatively high indicator should prepare well for a second wave; and overlaps of regions showing high PM2.5 and high obesity indicators would suggest an "orange warning status". The red warning status would be for those regions/countries where there an overlap of high PM2.5, high obesity figures and a high share of elderly people in the overall population.

Given the nature of a pandemic and the potential cross-border diffusion of epidemics, respectively, it is clear that every national policy response and health system reform in OECD countries – as well as in other countries (assuming similar findings as in OECD countries) – has elements of a multi-country/global international public good. The economic logic thus suggests that countries should join forces in part of epidemic prevention health care expenditures. Particular attention should be paid to sharing the costs of anti-epidemic pharmaceutical and medical R&D. The OECD countries should come up with a new approach and a special funding agency here where the OECD's outreach program – e.g. including non-member countries such as India and China – could be a starting point to also include some other countries in a strategic multilateral approach.

One may emphasize that the rather homogenous country group of OECD countries should find it easier to create an international health policy cooperation club with joint funding for international public goods than the economically much more heterogenous G20 group. To the extent that one ultimately wants to realize a global public good at the UN level – including all countries of the world – a lead initiative of the OECD could still be useful in order to generate sufficient momentum to achieve the provision of a global public good in a rather fast two-stage approach. A direct UN approach might also have some advantages, but there is a risk that heterogenous interests and the high number of countries involved would in the end mean a delayed provision of the global public good compared to the two-stage approach - or a three-stage approach: OECD-G20-UN (WELFENS, 2020b).

The fatality-increasing role of obesity points out to a broad global need in the field of development policy not simply to push for an economic catching up of the global South which often goes along with a spreading of certain Western nutrition styles. Anti-obesity goals and an explicit emphasis on more sports activities for all generations as well enhanced company-based health and fitness programs should become a general element of catching-up policies. In the OECD countries themselves, policy initiatives for reducing obesity problems should follow a similar logic of better nutrition – such as encouraging the consumption of vegetables and fresh fruits as well as an emphasis, and more information, on low fat and low sugar products – and more sports. Institutionalized programs in schools, universities, the public administration and firms could be useful here, plus digital networking, which helps spreading relevant

information and activities. The WHO has intensified its anti-obesity programs since 2018, but OECD countries have not been very active to include the relevant initiatives in its working programs: there is room for stronger WHO-OECD cooperation in this field and many OECD member countries, given high levels of obesity, have reason to become more active here.

Finally, the ageing of Western societies and of the population in Japan is a major long-term challenge for future epidemics. Beyond population policy and immigration incentives, little can be done in most OECD countries to slow the ageing process. However, there is an important policy implication with respect to membership contributions in certain international organizations. Given the international differential in terms of the ageing of populations of OECD countries (or UN member countries), one may argue that countries with a rather high ratio of the population aged 65 and over should contribute over-proportionately to the provision of international public goods in the field of prevention against and fighting of epidemics. So far in international organizations, the share of the elderly population plays no role in terms of the funding formula; the WHO could be the first organization where this aspect, emphasized in the research presented here, should have appropriate consequences. In a similar logic, one could argue that countries/regions with high PM2.5 indicators should also face higher contribution rates. As the regressions in the appendix – with significant Global Health Security indicators in two equations – suggest that an advanced health and health insurance system will bring about lower fatality ratios, the GHS index positioning of the respective country could go along with a contribution bonus to the WHO and possibly other international organizations. The incentives from such modified contribution rates could clearly encourage welfare-enhancing political reforms and thus contribution formulas to international organizations could have a positive impact of global welfare in the long run. A broader analysis of UN countries is, however, required in a next empirical research step.

At the bottom line, it is clear that more research is needed, but the empirical findings presented could indeed be a useful starting point in the international economic and environmental coronavirus research. The broader research challenges in many ways will also require enhanced interdisciplinary research which would, of course, include the medical sciences on many topics. Both internationally comparative research, regional analysis, as well as spatial regression analysis for cities could be crucial – see, for example, for New York (CHEN ET AL., 2020); among the findings for New York, using spatial regression analysis, one may mention that many contact-intensification points, including grocery shop density, green space density and median distance travelled plus, paradoxically, POIs of medicine density turned out to have a positive significant impact on infections. In a more international view, intensive contacts through travelling – possibly related to trade, foreign investment or tourism – could be critical epidemic diffusion points which could indicate that the shadow price of economic globalization might be higher than traditionally considered. In a nutshell, the urban centers of globalization around the world could pay a higher price in a COVID-19 environment than less densely populated cities, regions and countries. Here, and in the internationally comparative environmental quality dimensions, much future coronavirus research could be expected. As regards conclusions for policymakers, the suggested implications of our regression findings for dealing with a potential second wave of infections are already highly sensitive to being picked up quickly in the public debate.

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Appendix

Table 5: Correlation Matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Deaths/ million	1.00									
(2)	Cases/ million	0.65***	1.00								
(3)	% above 65	0.21	-0.11	1.00							
(4)	% overweight	0.23	0.27	-0.27	1.00						
(5)	PM2.5 in largest city	-0.15	-0.25	-0.24	-0.24	1.00					
(6)	% smokers	-0.04	-0.11	0.19	0.07	0.36*	1.00				
(7)	GHS Index	0.35*	0.08	0.24	-0.02	-0.38*	-0.28	1.00			
(8)	Herd immunity	0.41*	0.19	0.13	0.06	-0.20	-0.14	0.43**	1.00		
(9)	FDI openness	0.23	0.24	0.03	0.05	-0.13	0.08	-0.06	0.22	1.00	
(10)	Mean policy stringency	0.23	0.00	-0.07	0.26	0.38*	0.30	-0.18	-0.41*	-0.00	1.00

n=36, t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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