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ORIGINAL PAPER

The Effect of Pollution on the Spread of COVID-19 in Europe

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Abstract
This study investigates empirically how air pollution in earlier periods as measured by three air pollutants, namely NO_2, PM_{10}, and $PM_{2.5}$ may have affected the spread and fatality of COVID-19 in 31 European countries. Using panel data with fixed effects to examine the relationship between previous exposure to air pollution and COVID-19 new cases and COVID-19 deaths, we find that previous air pollution levels have both acted as an important factor in explaining the COVID-19 spread and its high fatality rate. This result may explain the negative impact that these pollutants may have on health and in particular on the respiratory functions that are mainly attacked by the virus.

Keywords COVID-19 Cases · COVID-19 Deaths · Air Pollution · Panel Analysis

Introduction

The highly infectious nature of the COVID-19 virus made it spread to the rest of the world within months since the first cases appeared in late 2019 in Wuhan, China. All European countries had at least one case by March 2020, with Italy, France, Spain and the United Kingdom being the countries that suffered most from the virus. Their high number of COVID-19 cases by the end of March 2020, combined with the high number of cases in the rest of Europe, made the continent the active epicenter of the pandemic. An important question that naturally arises in this context is the effect that previous environmental degradation may have had on the spread of the virus. It is common knowledge that long term

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exposure to high air pollution levels leads to many health problems especially related to lung diseases. In that case, people might be more vulnerable to the new virus leading to easier and faster spread of COVID-19. In addition, under those circumstances, the virus might result in more severe outcomes for the health of infected people, leading even to death[1]. We are mainly interested in exploring the effect of environmental pollution on the number of COVID-19 cases and deaths in European countries. In particular we want to see whether higher previous air pollution levels can lead to a significant change to the course of the spread of the virus through their potential negative impact on the functioning of the lungs and the respiratory system. The present study investigates how previous pollution levels affect the spread and the effects of the COVID-19 virus in Europe, using data from before and after the beginning of the virus for NO_2, $PM_{2.5}$ and PM_{10}. Our purpose is to examine whether past air pollution levels have had an impact on COVID-19 cases and deaths as we aim to offer some additional evidence to an already fast developing literature that mostly relies on simple descriptive tools by adding a more formal empirical study on the topic.

The structure of that paper is as follows: in "Literature Review" we present the already existing literature on that topic, in "Model" we present the data we are using in our analysis as well as the econometric method we base our results on, and in "Results" we show our results. Finally, in "Conclusion" we include our concluding remarks. In the online appendix we provide additional supporting evidence where we trim the data from possible outliers.

Literature Review

The literature on the COVID-19 and the environment nexus has mainly examined the positive effects of such policies as strict lockdowns that contributed to a cleaner environment. Air quality improvement, water pollution mitigation and reduction in carbon emissions due to travel restrictions, are also some additional positive impacts that the virus has had on the environment, especially in China. For example (Wang and Su 2020) and (Chen et al. 2020) focused on the COVID-19 outbreak in China and its results on air pollution and mortality rates. Similarly (Berman and Ebisu 2020) using data for NO_2 and $PM_{2.5}$ as well as satellite data taken from NASA for the United States, compared the air pollution levels before and during the COVID-19 pandemic and found a significant pollution reduction. Similar results for European countries are (Zambrano-Monserrate et al. 2020; Cheval et al. 2020; Briz-Redón et al. 2021) and (Kasioumi and Stengos 2021) among others.

There are only a few papers so far in the literature that have studied the relationship between environmental quality and COVID-19 outcomes and almost none of them have used formal statistical analysis beyond descriptive statistics. Wu et al. (2020b) showed that long term exposure to air pollution like $PM_{2.5}$ can lead to health problems associated with the lungs, which can then cause more severe COVID-19 outcomes or even death for those affected by the virus. Xu et al. (2020) focused on 3,739 global locations and 1,072 global cities and studied whether and if the weather conditions and the air pollution in those cities can affect the spread of the COVID-19 virus. They found that there is a weak positive correlation between SO_2, O_3, wind speed, air pressure and the spread of the virus. On the other hand, the relationship between COVID-19 transmissions and temperature is negative

[1] Evidence shows that early innervation from the government of a country can slow down the growth rate of deaths related to COVID-19, see Dergiades et al. (2020)

while it is U-shaped with outdoor ultraviolet exposure. The way that rainfall affects the COVID-19 outbreaks was studied by Kapoor et al. (2020), who showed that earlier social distancing due to the weather condition leads to a reduction on both new cases and deaths, meaning that other random effects that might take place early in a COVID-19 outbreak, can have significant effects on its course and its duration. Paraskevis et al. (2020) offered a review paper on that topic mentioning that the relationship between COVID-19 and air quality is complicated and cannot be explored in detail for now due to the lack of sufficient data. However, they mention that COVID-19 and temperature as well as humidity are linked through a negative relationship.

Wilson (2020) studied the effect of weather on COVID-19 cases and deaths for the US. The correlation between the virus' cases and deaths, and the temperature is negative meaning that during winter, the effects of the virus on people's health are more dramatic than during the summer. In addition, Wu et al. (2020a) found a strong connection between air pollution and COVID-19 deaths in US, as a small increase of 1 microgram per cubic meter of air ($\mu g/m3$) in $PM_{2.5}$ relates to a high increase in the virus-related deaths by 8%. Another study connecting the spread of COVID-19 with the air quality is the one of Travaglio et al. (2021), where they investigate the case of England. Their results show that NO_2 and $PM_{2.5}$ are very important pollutants affecting the spread of the virus, as NO_2 is positively related to COVID-19 mortality and an increase of $PM_{2.5}$ leads to an increase of COVID-19 cases. Moving on to the case of Northern Italy, one of the most polluted area in Europe, Conticini et al. (2020) found that air pollution can be a great co-factor of higher level of deaths due to COVID-19. According to them, higher air pollution leads to chronic health conditions even to healthy and younger people, allowing the new virus to infect them easier and even lead to death. Gupta et al. (2020) focused on nine different Asian countries and showed that past exposure to high level of air pollution over a long period, specifically of $PM_{2.5}$, affects the mortality of COVID-19 positively. In other words, air pollution and COVID-19 mortality are positively correlated, even though this correlation does not hold for the case of PM_{10}. For the case of China, Martelletti and Martelletti (2020) found that higher air pollution level affects positively the fatality of COVID-19, with the relationship between those two variables to be linear.

Model

Data

To measure the air pollution level, we are using data on NO_2, $PM_{2.5}$, and PM_{10} which are the most common local air pollutants. NO_2 is mainly produced from vehicles, industrial emissions, construction and any other operation that burns fossil fuels. The main sources of PM_{10} and $PM_{2.5}$ are burning wood, oil, or coal (forest fires, fireplaces, fuel-burning heaters), cooking, driving vehicles (car, snowmobile, bus), smoking and volcanic eruptions. Those data were taken from the European Environmental Agency (EEA) and they are all measured in micrograms per cubic meter of air ($\mu g/m3$). The database includes data for most European countries as they collect their data using approximately 3,000 monitoring stations of all types in many cities across Europe, for the years between 2018 and 2021. The data are measured on an hourly basis which is then used to calculate a daily average of each station. Those daily averages are finally used to calculate a weekly and monthly average too. For our analysis we will use the monthly data coming from all available cities, but we will

Table 1 Descriptive statistics of the panel dataset

	Mean	Variance	Median	Range
NO_2	5.101	2.014	5.094	1.609 - 8.288
$PM_{2.5}$	4.195	2.082	3.989	1.099 - 7.396
PM_{10}	4.998	1.984	4.836	2.079 - 7.881
Monthly new Cases	9.957	4.846	10.069	3.850 - 14.102
Monthly new Deaths	5.501	6.836	5.778	0.000 - 10.397

gather them for each country separately since we want to focus on the effect of COVID-19 on the entire country, not in specific cities[2]. Finally, we are testing each pollutant separately.

Those three air pollutants are the most important ones for our analysis as they are local pollutants and extremely dangerous for health. In that way we can study both the effects that these pollutants have had on people's health after the emergence of the virus. Specifically, NO_2 is a highly dangerous air pollutant which can reduce the lung function leading to higher asthma attacks, worsen cough and wheezing. In addition, it increases the likelihood of hospital admissions and it is the cause of asthma in children. Moving on to particulate matter, PM_{10} are tiny inhalable particles in the air that are 10 micrometers or smaller in width, while $PM_{2.5}$ are less than or equal to 2.5 micrometers. Their tiny size make them extremely dangerous as they can easily be inhaled, affecting the lungs, damaging the respiratory track, and even the bloodstream, leading to serious health problems. All the above air pollutants are highly linked to several lung diseases and are the focus of this study.

The other variables we use in our analysis are COVID-19 data and specifically data on new cases and deaths for all European countries from the beginning of COVID-19 till March of 2021. Those data are daily data from Our World in Data and they are measured per million people. To avoid noise coming from daily data, we have created the corresponding monthly data for each country separately, to be in line with the air pollution data.

The panel dataset we created consists of 31 countries[3], including data for the COVID-19 cases and deaths for the period between July, 2020 to March, 2021, as well as data for air pollution for a two years lagged period, between July, 2018 to March, 2019. We include a two years lagged period between our data, to allow for the air pollution to show the possible negative effects it may have on people's health. The following table (Table 1) shows the descriptive statistics of our panel dataset which includes the three pollutants (NO_2, PM_{10}, $PM_{2.5}$), and the COVID-19 new monthly cases and deaths for each country for the period mentioned above, and includes the mean, variable, median, and range[4].

[2]We have included country averages that submerge the specific city effects in order to tackle the possible cross sectional dependence that would exists if we were using cities separately.

[3]The European countries we are using in our analysis are the following: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. All the data are publicly available.

[4]Please note that the descriptive statistics are calculated for the logarithmic form of the data, which we use in our regressions to interpret the marginal responses in percentages.

Empirical Method

The main purpose of this study is to investigate if previous pollution levels can influence the growth and fatality of the COVID-19 virus. We are using two different panel data sets that include 31 European countries for the period between 2020 to 2021, one for the COVID-19 cases and one the reported deaths, while for pollution levels we use the period between 2018 and 2019. All our data are expressed in logarithmic form to interpret the marginal responses in percentages.

There are some papers supporting that long term exposure to air pollution can increase the chance of having health problems leading to higher COVID-19 cases and more severe COVID-19 outcomes, as Wu et al. (2020b) and Wu et al. (2020a). Hence, it is of crucial importance to research how previous air pollution levels affect the new cases of the COVID-19 virus. For that reason, we investigate the effect that previous air pollution levels up to two years has had on COVID-19 cases. We are excluding the first six months of the pandemic, as the virus was not widely spread and as such we include the months of July of 2020 till March of 2021 for the COVID-19 cases and the months July of 2018 to March 2019 for the air pollution data. We are using country fixed effects as well as a time trend variable. Our data are measured on a monthly basis and we will have three different linear regressions for each air pollutant (NO_2, PM_{10}, $PM_{2.5}$), described by the following general regression:

$$log(cases)_{it} = \beta_0 + \alpha_i + \beta_1 * log(pollutant_k)_{i(t-24)} + \beta_2 * t_{it} + u_{it} \quad (1)$$

were cases are the new monthly COVID-19 cases, α refers to the country fixed effects, pollutant refers to one of the three different air pollutants we are using separating them by the letter k, t stands for the time trend while u is the error term. As we can see here, the right hand side of our regression and specifically the air pollution data have a lag of 24 months, as it is important to let a significant amount of time to pass before we start seeing the effects of air pollution on human health and guard against possible endogeneity.

We would also like to examine how high previous air pollution levels may lead to more fatalities in COVID-19 cases. Both Conticini et al. (2020) and Martelletti and Martelletti (2020) found that previous exposure to significant air pollution and COVID-19 deaths are positively correlated. As people become more vulnerable to health problems after long time exposure to air pollution, COVID-19 virus can lead to more destructive outcomes as people are unable to fight against it. For this reason we are using a similar dataset as in the previous regression but using deaths instead of cases now. Particularly, we include data for the same months as before for both COVID-19 deaths and air pollution allowing for two years lag period to pass to be able to see the effects of air pollution on human's health. We include country fixed effects and a time trend variable, as well as three different regressions for each air pollutant separately which can be described by the following general form:

$$log(deaths)_{it} = \beta_0 + \alpha_i + \beta_1 * log(pollutant_k)_{i(t-24)} + \beta_2 * t_{it} + u_{it} \quad (2)$$

were deaths represents deaths coming from the COVID-19 virus, α shows the country fixed effects, pollutant refers to one of the three different air pollutants we are using separating them by the letter k, t stands for the time trend while u is the error term.

We want to emphasize that in our analysis we chose the longest available lag period of previous emissions levels from the current health problems that arose during COVID-19, to make the temporal separation more distinct and try to mitigate any endogeneity issues.

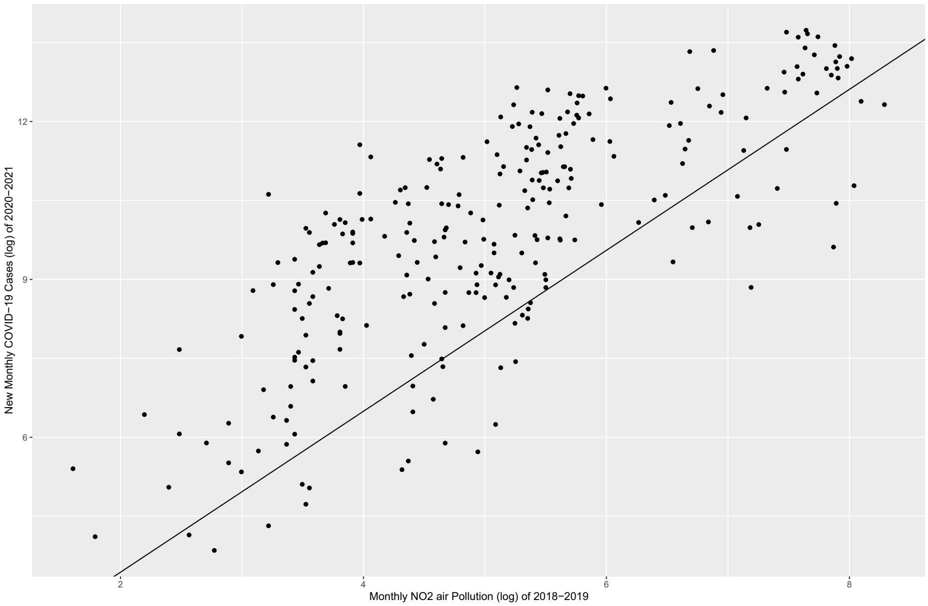

Fig. 1 Correlation Between new Monthly COVID-19 Cases and Previous NO_2 Pollution in 31 European Countries

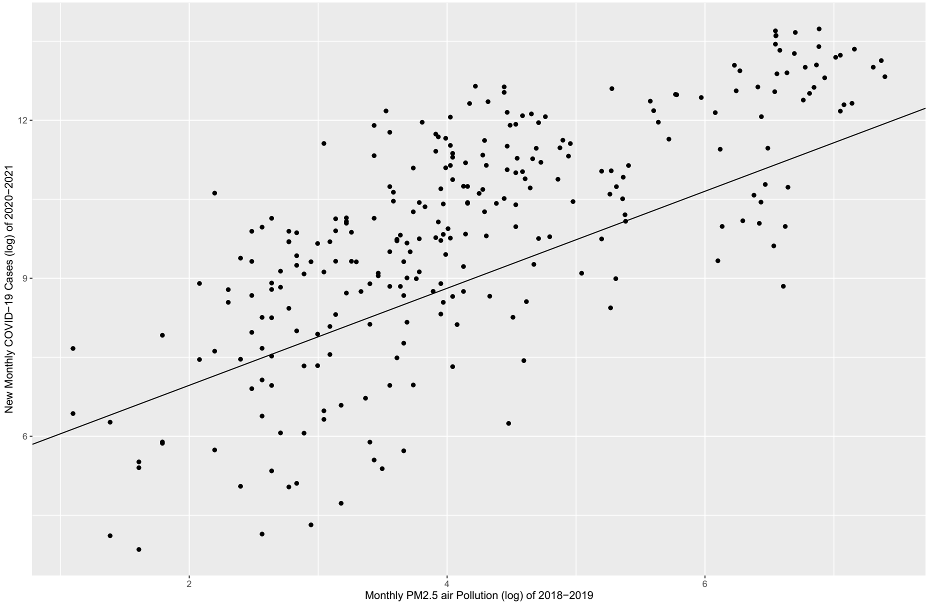

Fig. 2 Correlation Between new Monthly COVID-19 Cases and Previous $PM_{2.5}$ Pollution in 31 European Countries

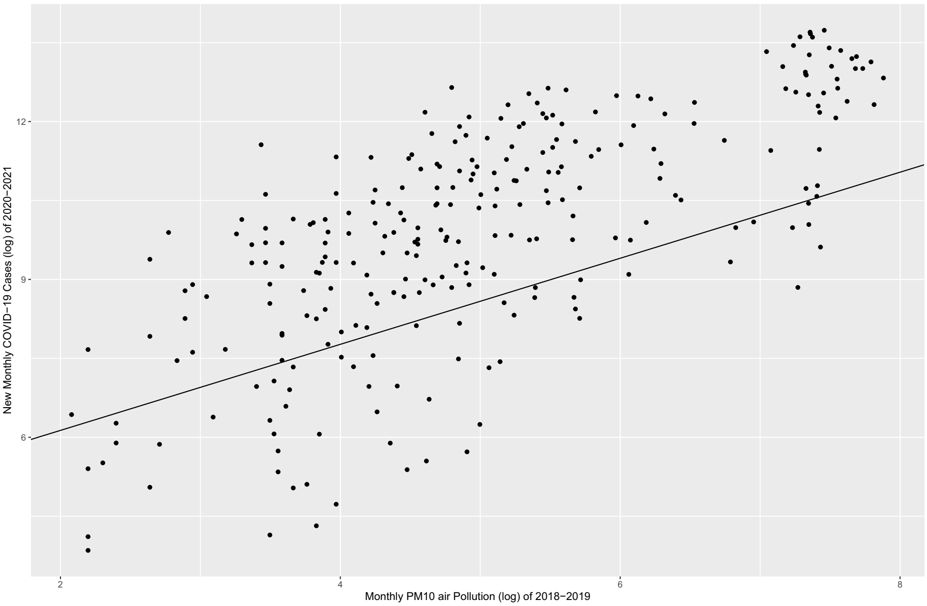

Fig. 3 Correlation Between new Monthly COVID-19 Cases and Previous PM_{10} Pollution in 31 European Countries

Table 2 Estimated results from the lagged panel data model with fixed effects for the lagged effect of NO_2 on COVID-19 cases

Variable	Estimate	Std. Error	t value	Pr(> |t|)
Intercept	0.37638	1.76939	0.213	0.8317
Lagged NO_2 effect	1.52941	0.32875	4.652	5.45e-06 ***
Time trend	0.31848	0.02950	10.797	< 2e-16 ***
N	272			
R^2	0.8109			

*** $p = 0$, ** $p < 0.001$, * $p < 0.01$, . $p < 0.05$, $p < 0.1$

Table 3 Estimated Results from the Lagged Panel Data Model with Fixed Effects for lagged effect of $PM_{2.5}$ on COVID-19 cases

Variable	Estimate	Std. Error	t value	Pr(> |t|)
Intercept	5.12515	0.90228	5.680	3.91e-08 ***
Lagged $PM_{2.5}$ effect	0.92122	0.22995	4.006	8.26e-05 ***
Time trend	0.35428	0.02657	13.335	< 2e-16 ***
N	272			
R^2	0.8067			

*** $p = 0$, ** $p < 0.001$, * $p < 0.01$, . $p < 0.05$, $p < 0.1$

Table 4 Estimated results from the lagged panel data model with fixed effects for lagged effect of PM_{10} on COVID-19 cases

Variable	Estimate	Std. Error	t value	Pr(> |t|)
Intercept	4.49549	1.58157	2.842	0.00487 **
Lagged PM_{10} effect	0.81778	0.31898	2.564	0.01097 *
Time trend	0.37503	0.02632	14.250	< 2e-16 ***
N	272			
R^2	0.7992			

$^{***}p = 0$, $^{**}p < 0.001$, $^{*}p < 0.01$, $.\ p < 0.05$, $p < 0.1$

Results

Following the discussion in "Empirical Method", we are able to find a positive correlation between previous air pollution and the spread of COVID-19 as well as previous air pollution levels and the fatality of the virus for 31 European Countries. We will present the results from both panel analyses for the relationship between air pollution and COVID-19 cases as well as air pollution and COVID-19 deaths.

Air pollution leads to potentially many health problems leaving people more vulnerable to new diseases, such as COVID-19 which is of a very infectious nature, but it would take some time for these negative health effects to emerge. The results can be seen in the following three plots (Figs. 1, 2 and 3) and three tables (Tables 2, 3 and 4) all of which support a positive correlation between past pollution levels and current amount of COVID-19 cases.

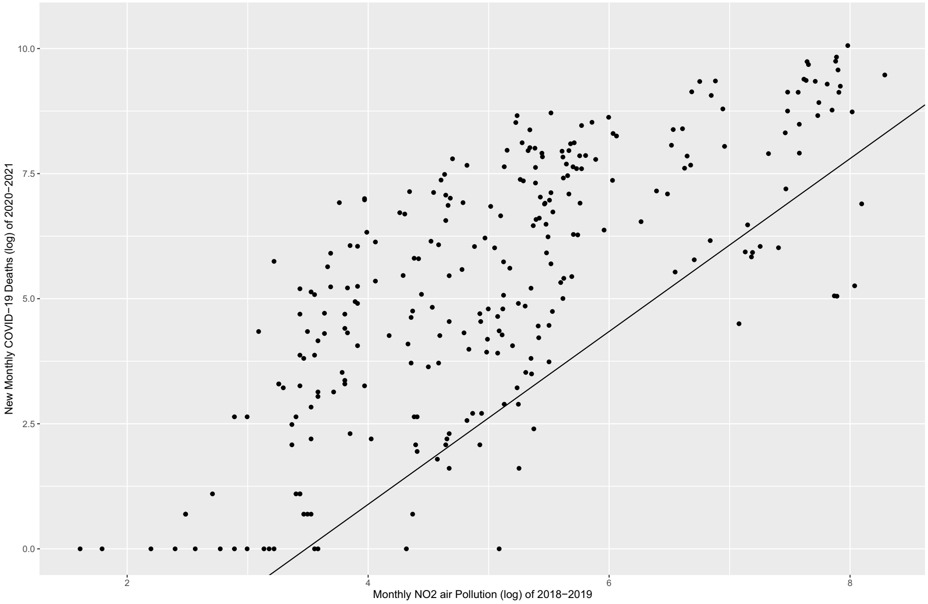

Fig. 4 Correlation Between new Monthly COVID-19 Deaths and Previous NO_2 Pollution in 31 European Countries

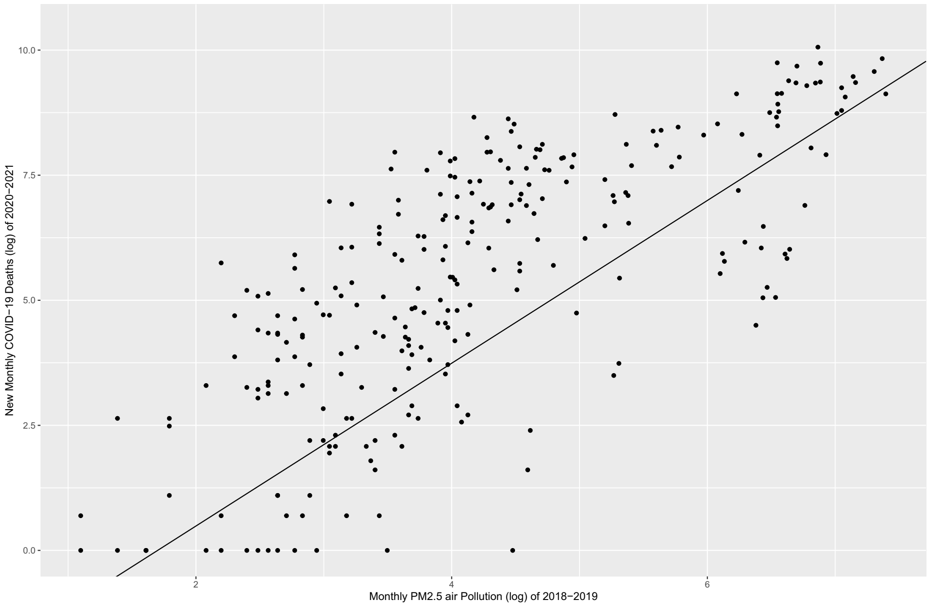

Fig. 5 Correlation Between new Monthly COVID-19 Deaths and Previous $PM_{2.5}$ Pollution in 31 European Countries

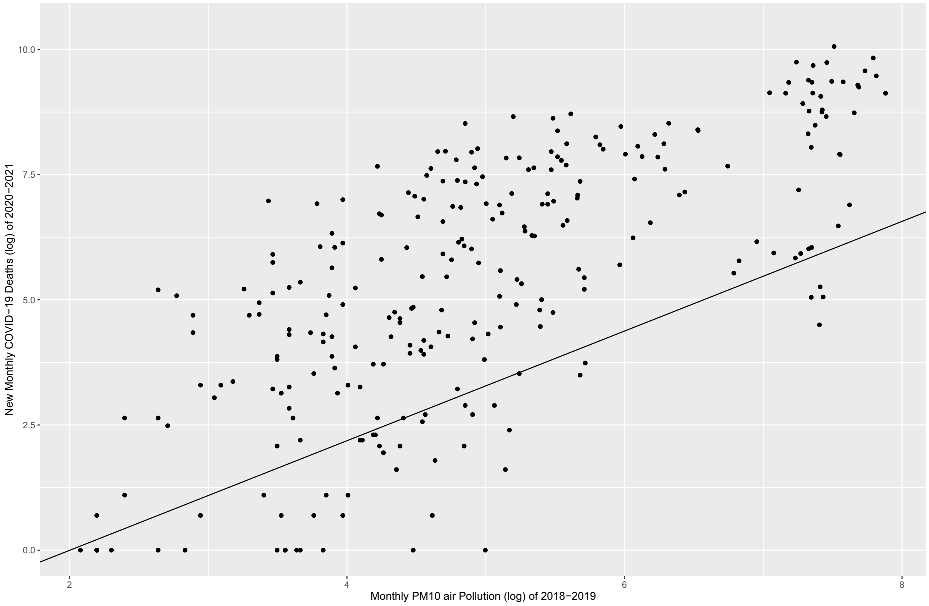

Fig. 6 Correlation Between new Monthly COVID-19 Deaths and Previous PM_{10} Pollution in 31 European Countries

Table 5 Estimated results from the lagged panel data model with fixed effects for the lagged effect of NO_2 on COVID-19 deaths

Variable	Estimate	Std. Error	t value	$Pr(>\|t\|)$
Intercept	−6.02205	1.90078	−3.168	0.00173 **
Lagged NO_2 effect	1.72775	0.35316	4.892	1.84e-06 ***
Time trend	0.42981	0.03169	13.564	< 2e-16 ***
N	272			
R^2	0.8457			

$^{***}p = 0$, $^{**}p < 0.001$, $^{*}p < 0.01$, $.\ p < 0.05$, $\ p < 0.1$

It is also important to examine how previous exposure to air pollution can affect the fatality outcomes of COVID-19, and for that part of our analysis we are using a similar dataset as in the previous case including deaths instead of cases. From the following plots and tables (Figs. 4, 5 and 6 and Table 5, 6 and 7) we see that there is a significant positive correlation between the variables. In other words, previous exposure to air pollution leads to more severe COVID-19 outcomes leading to an increase of deaths caused by the virus. Specifically, we see that if our previously exposure to NO_2 could increase by 10%, that would lead to a 17.2% increase in COVID-19 deaths now.

Our results from the above regressions can explained both by the nature of the virus and the side effects of air pollution on humans' health. All three air pollutants we included in our study can easily lead to health problems related to lungs, as NO_2 can reduce the lung capacity and lead to asthma, while both $PM_{2.5}$ and PM_{10} are tiny particulate matter which can easily be inhaled leading to damages of air sacs. Similarly, COVID-19 is a virus that affects cells along airways leading to serious inflammations and lung damages. In that way, people who were exposed to air pollution in the past, are already more vulnerable, allowing COVID-19 to spread easier and faster but also have fatal results. As we can see, air pollution and COVID-19 are closely related to lung damages which explains our previous results.

Table 6 Estimated Results from the Lagged Panel Data Model with Fixed Effects for lagged effect of $PM_{2.5}$ on COVID-19 deaths

Variable	Estimate	Std. Error	t value	$Pr(>\|t\|)$
Intercept	−2.7660179	0.9168053	−3.017	0.002830 **
Lagged PM_{10} effect	1.6267476	0.2336557	6.962	3.24e-11 ***
Time trend	0.4412133	0.0269955	16.344	< 2e-16 ***
N	272			
R^2	0.8589			

$^{***}p = 0$, $^{**}p < 0.001$, $^{*}p < 0.01$, $.\ p < 0.05$, $\ p < 0.1$

Table 7 Estimated results from the lagged panel data model with fixed effects for lagged effect of PM_{10} on COVID-19 deaths

Variable	Estimate	Std. Error	t value	Pr(> |t|)
Intercept	−2.19512	1.69372	−1.296	0.19622
Lagged $PM_{2.5}$ effect	1.09517	0.34160	3.206	0.00153 **
Time trend	0.48848	0.02818	17.332	< 2e-16 ***
N	272			
R^2	0.8372			

$***p = 0$, $**p < 0.001$, $*p < 0.01$, $. \ p < 0.05$, $p < 0.1$

Conclusion

There are some papers supporting the view that previous exposure to high levels of air pollution affects the spread and mortality of the virus, see Wu et al. (2020b), Conticini et al. (2020), and Martelletti and Martelletti (2020) among others. Air quality is a significant factor affecting people's health and it can lead to many health care problems when the pollution increases. In addition, it leaves people more vulnerable to new threats and viruses, especially those with high contaminating nature as is the COVID-19. Hence, higher exposure to previous air pollution can also affect the outcomes of the COVID-19 pandemic and so it is important to investigate the relationship between them.

Our study investigates the effects that previous air pollution levels have on the COVID-19 pandemic. Specifically, we are interested in the effects that exposure to air pollution in the past has on the course of the virus, particularly to the spread rate and the fatality rate. Using a panel analysis with two years lag on the data of air pollution, for 31 European countries and having data for 2020 till 2021 for the COVID-19 cases and deaths and data for 2018 and 2019 for air pollution, we find that higher previous pollution levels affect the cases of the virus positively. Similarly, we are able to find a significant positive correlation between exposure on previous air pollution and COVID-19 deaths.

Air pollution can greatly affect the health and well being of people, as it can lead to many health problems especially related to lung problems. Specifically, the pollutants we are using in this study are local pollutants stemming mainly from burning fuel and they are extremely dangerous for people's health, as they destroy the respiratory system. That allows COVID-19 to infect people easier as they are more vulnerable, leading to a more rapid spread of the virus which is also accompanied by more disastrous results, as people are unable to defeat the virus something that might also lead to a faster death.

Supplementary Information The online version contains supplementary material available at doi:10.1007/s41885-021-00099-y.

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