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Asymmetric link between environmental pollution and COVID-19 in the top ten affected states of US: A novel estimations from quantile-on-quantile approach

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ABSTRACT

This study draws the link between COVID-19 and air pollution (ground ozone O₃) from February 29, 2020 to July 10, 2020 in the top 10 affected States of the US. Utilizing quantile-on-quantile (QQ) estimation technique, we examine in what manner the quantiles of COVID-19 affect the quantiles of air pollution and vice versa. The primary findings confirm overall dependence between COVID-19 and air pollution. Empirical results exhibit a strong negative effect of COVID-19 on air pollution in New York, Texas, Illinois, Massachusetts, and Pennsylvania; especially at medium to higher quantiles, while New Jersey, Illinois, Arizona, and Georgia show strong negative effect mainly at lower quantiles. Contrarily, COVID-19 positively affects air pollution in Pennsylvania at extreme lower quantiles. On the other side, air pollution predominantly caused to increase in the intensity of COVID-19 cases across all states except lower quantiles of Massachusetts, and extreme higher quantiles of Arizona and New Jersey, where this effect becomes less pronounced or negative. Concludingly, a rare positive fallout of COVID-19 is reducing environmental pressure, while higher environmental pollution causes to increase the vulnerability of COVID-19 cases. These findings imply that air pollution is at the heart of chronic diseases, therefore the state government should consider these asymmetric channels and introduce appropriate policy measures to reset and control atmospheric emissions.

1. Introduction

In general, pandemics do not only increase concerns regarding public health but also instigate ruinous socio-economic crises in the disease-ridden regions. In the present century, human civilization has witnessed several pandemics such as H1N1 in 2009 in Mexico, Ebola in 2014 in West Africa, Polio in 2014 in Middle East, Zika virus in Brazil in 2016 and Ebola again in 2019 in the Democratic Republic of Congo. These outbursts internationally ensued in a huge number of mortalities, diseases, and cost billions of dollars (Allocati et al., 2016; Fan et al., 2019). Since the last month of the year 2019, the world has also been confronted with another epidemic termed as COVID-19 (contagious disease) originated in Wuhan, China (Zhu et al., 2020; Huang et al., 2020). Regardless of the excessive efforts by the Chinese Government in the isolation of Wuhan City from the rest part of China, the epidemic rampantly surrounded the whole sphere including Asia, Europe, Africa, and America, and soon acknowledged as a pandemic by the World Health Organization (World Health Organization, 2020).

The outburst has uncontrollably outstretched to 210 countries and exceeds 16, 465, 707 confirmed infected cases while 653,862 reported
cases of deaths as on July 29, 2020 (GIS, 2020). COVID-19 equally spread in both developed and developing countries that have not been completely eradicated, even growing trend is observed in some regions (Bai et al., 2020; Lai et al., 2020), mainly due to the unavailability of the disease-resistant drug and vaccine. Nevertheless, the situation of top ten most affected countries; United States, Brazil, United Kingdom, Mexico, Italy, India, France, Spain, Peru, Iran, and Russia are imperiled to the peak and gigantic death toll even the United States solely recounted skyrocketing figure such as 4,515,586 confirmed cases and 152,726 deaths as of July 29, 2020 (Worldometers, 2020).

Apart from becoming the huge risk to the worldwide public health and severely smashing the economy of the host countries (Chakraaborty and Maity, 2020), COVID-19 is refining the environmental quality in response to the temporary suspension of global economic activities (Zambrano-Monserrate et al., 2020; Tobias et al., 2020; Collivignarelli et al., 2020). Globally, it has been proven by satellite images and ground data that air pollution in the form of nitrogen dioxide (NO2) emission in many parts has dropped in a way that the earth’s stratosphere ozone layer is recovering (NASA, 2020). The upper atmosphere of the earth (stratosphere) is covered by the Ozone layer that helps to prevent the earth from ultraviolet rays. However, the ground-level O3 (tropospheric) is considered as a secondary air pollutant produced by composite photochemical reactions encompassing radiations of sun and precursors of ozone (US EPA, 2020a; 1996b).

Since the detection of realms cases of the COVID-19, the rigorous and strict measures that have been executed instantly after the widespread of the COVID-19 have had an outstanding environmental effect by drastically cutting the emissions of pollutants specifically, NO2 concentration in China as well as in numerous countries of Europe and US (Shrestha et al., 2020; Zhang et al., 2020). The recent studies by Muhammad et al. (2020), Dutheil et al. (2020), and Wang and Su (2020) identified the reduction of NO2 emissions ranging between 20% and 30% in the USA, China, Spain, France, and Italy. Similarly, Kanniah et al. (2020) proposed that industrial and anthropogenic activities cessation due to COVID-19 lead to a major reduction of harmful pollutants which noticeably stemmed from the retrieval of ecosystems and most prominently O3 pollution has been found reducing up to some extent.

Consequently, the state nowadays is regarded as a “return” for ecosystem and humans, given the ecosystem a “recuperative time” with decreased interference of humans in the natural environment.

Looking at the flip side relationship between air pollution and COVID-19, prevailing studies in the context of virus-related contagions like SARS, MARS, and COVID-19 found that the exposure to air pollution exacerbates the vulnerability of lungs infections that lead to host morbidity and mortality, and overall exert an adverse impact on the public health status globally (Manisalidis et al., 2020; Pothirat et al., 2019). Surprisingly, it has been argued that COVID-19 is also transmitted through the medium of air from China to other regions, and air pollution is identified as a coronavirus carrier (Wu et al., 2020a, 2020b). Contrary Bontempi (2020) failed to find the evidence for airborne diffusion of COVID-19 virus from the case study of Lombardy (Italy). Many previous studies also claimed that air pollutants like carbon monoxide, NO2, particulate matter (PM) in dissimilar fractions such as PM2.5, PM10, and PM0.1μm, polyacrylum hydrocarbons, volatile organic compounds, and O3 pollution, etc. Adversely affect the immune and cardio-respiratory systems of the host by altering their disease nexus are somewhat novel and, in our study, we are tracking the relationship in two ways i.e. anticipated in exploring not only the impact of worseness of COVID-19 due to ozone O3 pollution (Bayram et al., 2001). Ozone pollution and contagion disease nexus are somewhat novel and, in our study, we are tracking the relationship in two ways i.e. anticipated in exploring not only the impact of COVID-19 on the environmental quality but also elucidating the risk of worseness of COVID-19 due to ozone O3 pollution as a measure of environmental deterioration.

2. Channels between COVID-19 and air pollution

2.1. Impact of COVID-19 on air pollution

Air pollution and COVID-19 are both well known in causing or exacerbating respiratory distress, and recent studies suggest that the two factors may interact (Hadei and Naddafi, 2020). The pollution-reducing effect of COVID-19 is mainly attributed to the measures taken by the

| Top 10 affected (COVID-19 Cases) states and Lockdown status. |
|-------------------------------------------------------------|
| States          | Confirmed cases | Deaths | Death_100k | 1st COVID-19 case reported | 1st Lockdown | Lockdown end | Decrease in Mobility |
| California      | 460,550         | 8445   | 21         | 1/26/2020                  | 3/19/2020    | 5/25/2020    | 4.04% |
| Florida         | 427,698         | 5931   | 28         | February 3, 2020           | 3/20/2020    | April 5, 2020| 1.65% |
| New York        | 413,834         | 32,329 | 359        | February 3, 2020           | 3/22/2020    | 5/29/2020    | 2.39% |
| Texas           | 385,923         | 5713   | 20         | March 5, 2020              | February 4, 2020 | January 5, 2020 | 2.09% |
| New Jersey      | 179,812         | 15,804 | 177        | February 3, 2020           | 3/21/2020    | September 6, 2020 | 1.41% |
| Illinois        | 173,897         | 7608   | 60         | 1/24/2020                  | 3/21/2020    | 5/29/2020    | 3.08% |
| Georgia         | 170,843         | 3509   | 33         | March 3, 2020              | March 4, 2020 | 4/24/2020    | 2.44% |
| Arizona         | 163,827         | 3304   | 46         | 1/26/2020                  | 3/30/2020    | August 5, 2020 | 2.48% |
| Massachusetts   | 115,926         | 8536   | 124        | January 2, 2020            | 4/24/2020    | 5/18/2020    | 2.79% |
| Pennsylvania    | 109,384         | 7146   | 56         | June 3, 2020               | April 1, 2020 | 5/15/2020    | 4.07% |

Source: CDC Tracker access date: July 29, 2020a, 2020b.

a Retail, restaurant dining, houses of worship, entertainment, outdoor recreation, industries are opened. Food and drink bars, stadiums, and conventional halls are closed as per status on 8/13/2020. Lockdown information has been taken from the State’s official website and notifications compiled by NYT (2020) and USTODAY (2020).

b The share of residents leaving their homes was less than the seven days prior as on 8/13/2020.
respectively governments to restrict contiguous spread. Social distancing, discontinuity of business operation, or lockdown helps to flatten the COVID-19 curve (Bashir et al., 2020). In doing so, the US state government implement effective lockdown measures to limit travel, curtail mobility, and interaction of people. Table 2 shows the detail of statewide COVID-19 cases, lockdown time, and decrease in people movement, and interaction of people. Table 1 shows the detail of lower economic activity and subsequently decrease energy demand in the US by 9% compared to the same period in 2019. However, the emissions reduction effect of COVID-19 depends upon the depth and width of lockdown measures, indicating a 7% reduction in case of stringent confinement (full lockdown), while a 4% reduction in moderate confinement (partial lockdown) (Quéré et al., 2020).

### 2.2. Impact of air pollution on COVID-19

In addition to air pollution decreasing immune defenses and wane respiratory health (Manisalidis et al., 2020; Martelletti and Martelletti, 2020), it is evident that air pollution in the form of ground-level ozone \(O_3\) PM and \(NO_2\) can act as vectors for the spread and survival of airborne particles such as COVID-19 (Frontera et al., 2020 Sterpetti, 2020). According to WHO (2020), COVID-19 is a respiratory illness and the primary transmission route is through person-to-person contact and through direct contact with respiratory droplets generated when an infected person coughs or sneezes. Setti et al. (2020) estimated that air pollution in the form of a high concentration of PMs acts as vehicles for viral transmission, resultantly increase the number of morbidity and mortality in highly polluted territories in northern Italy. Similar results are echoes by Conticini et al. (2020) from Italian tertiaries. According to IHM (2020), northern Italy accounts for 80% of total deaths and 65% of Intensive Care Units admission, which is mainly attributed to higher air pollution in the region.

Based on the US cross country sample, Wu et al. (2020a, 2020b) estimated that 1 \(\mu g/m^3\) more pollution in the form of PM in the air corresponded to 8 percent more COVID-19-related deaths. This estimation is 16% greater than the prior estimations provided by Setti et al. (2020) from Italy, which is mainly ascribed to differences in population density and lockdown measures. Cole et al. (2020) provide compelling factors mitigate the level of environmental pollution by 25%–30% as compare to the previous years (Muhammad et al., 2020; Berman and Ebisu, 2020).

From Table 2, similar insights are observed at the global level, where energy demand significantly decreases during the lockdown period that translates into lower environmental pollution (Bashir et al., 2020; Muhammad et al., 2020). Global energy demand is set to fall by 5% in 2020, the largest decline since the great depression (IEA 2020). An intuitive study by Quéré et al. (2020) estimates a 17% average reduction in global emissions during the lockdown period by the end of April as compared to the same period in 2019. However, the emissions reduction effect of COVID-19 depends upon the depth and width of lockdown measures, indicating a 7% reduction in case of stringent confinement (full lockdown), while a 4% reduction in moderate confinement (partial lockdown) (Quéré et al., 2020).

### Table 2

Impact of lockdown on the global energy sector.

| Country | Lockdown Start | Lockdown End | Energy demand (ED) |
|---------|----------------|--------------|--------------------|
| Australia | March 23, 2020 | May 15, 2020 | ED ↓ approx. 8%–10% |
| Belgium | March 18, 2020 | April 19, 2020 | ED ↓ of industrial and commercial sector ↓ by 70% |
| China | January 23, 2020 | April 8, 2020 | ED ↓ by 8% (Jan & Feb compared to the same period in 2019) |
| France | March 17, 2020 | May 11, 2020 | ED ↓ by 6%–12% |
| Germany | March 20, 2020 | April 20, 2020 | ED ↓ by 4%–6% |
| India | March 25, 2020 | May 4, 2020 | ED ↓ by 30% |
| Italy | March 9, 2020 | May 4, 2020 | ED ↓ by 10.1% in March and 22% after 22nd March |
| Portugal | March 13, 2020 | April 11, 2020 | ED ↓ by 3%–5% |
| Singapore | April 7, 2020 | June 1, 2020 | ED ↓ 8%–9% |
| Spain | March 14, 2020 | April 25, 2020 | 3% ↓ (March), 20% ↓ (April) |
| Netherlands | March 16, 2020 | April 28, 2020 | Overall energy demand ↓ |
| UK | March 24, 2020 | May 11, 2020 | ED ↓ by 10% (after 23rd March) |

Source (AEMO, 2020; Rajvikram et al., 2020; S&P Global, 2020):

### Table 3

Results of descriptive statistics.

| Variables | Mean | Min | Max | Std. Dev. | Skewness | Kurtosis | Jarque-Bera |
|-----------|------|-----|-----|-----------|----------|----------|------------|
| **Panel A: COVID-19 Infected Cases** | | | | | | | |
| New York | 0.098 | 0.003 | 1.705 | 0.224 | 4.246 | 25.660 | 3220.883* |
| California | 0.072 | 0.006 | 0.410 | 0.082 | 2.022 | 6.886 | 173.027* |
| Florida | 0.094 | 0.001 | 1.099 | 0.153 | 3.364 | 17.865 | 1464.180* |
| Texas | 0.094 | 0.005 | 1.099 | 0.156 | 3.712 | 19.427 | 1787.312* |
| New Jersey | 0.091 | 0.098 | 1.099 | 0.176 | 2.816 | 12.266 | 646.602* |
| Illinois | 0.085 | 0.134 | 0.619 | 0.123 | 2.104 | 7.315 | 199.818* |
| Arizona | 0.088 | 0.008 | 0.693 | 0.131 | 2.278 | 10.632 | 490.160* |
| Georgia | 0.088 | 0.016 | 1.224 | 0.160 | 3.868 | 22.709 | 2465.620* |
| Massachusetts | 0.088 | 0.644 | 1.299 | 0.189 | 4.122 | 23.588 | 2441.028* |
| Pennsylvania | 0.087 | 0.138 | 1.099 | 0.159 | 3.346 | 17.267 | 1365.867* |
| **Panel B: Ozone O3 Pollution** | | | | | | | |
| New York | 0.001 | –0.779 | 0.722 | 0.243 | –0.073 | 4.598 | 14.170* |
| California | 0.001 | –0.591 | 0.531 | 0.183 | –0.269 | 3.672 | 14.077* |
| Florida | –0.003 | –0.711 | 0.693 | 0.211 | –0.163 | 4.183 | 8.287** |
| Texas | –0.004 | –0.762 | 0.758 | 0.224 | 0.388 | 5.000 | 25.300* |
| New Jersey | –0.005 | –0.693 | 0.661 | 0.237 | 0.182 | 4.017 | 6.423** |
| Illinois | 0.000 | –0.563 | 0.505 | 0.199 | –0.405 | 3.818 | 7.290** |
| Arizona | 0.001 | –0.393 | 0.313 | 0.104 | –0.225 | 4.420 | 12.206** |
| Georgia | 0.001 | –0.693 | 0.981 | 0.246 | 0.759 | 5.564 | 48.848** |
| Massachusetts | 0.004 | –0.759 | 0.651 | 0.292 | –0.415 | 4.278 | 12.779** |
| Pennsylvania | 0.002 | –1.44 | 1.15 | 0.27 | –0.61 | 10.57 | 323.50* |

Source: Author Estimations.

* And ** represent level of significance at 1% and 5% respectively.
evidence of a positive relationship between air pollution, and particularly PM$_{2.5}$ concentrations, and COVID-19 cases, hospital admissions, and deaths in the Netherlands. Their study estimated that a 1 μg/m$^3$ increase in PM$_{2.5}$ concentrations is associated with 9.4 more COVID-19 cases, 3.0 more hospital admissions, and 2.3 more deaths. These studies argued that higher exposure to a polluted environment increases the vulnerability of respiratory diseases and reduces the immune system thus inhabitants are more prone to get COVID-19 infection amongst
other diseases. Concludingly, the prevailing literature provides two channels; first, the transmission of COVID-19 is inflated with a higher level of pollution; second, exposure to a higher level of pollution weakens the immune system and caused respiratory diseases, which leads to higher vulnerability of COVID-19 infection and subsequent deaths.

3. Data and methodology

The current study draws a link between air pollution and COVID-19 pandemic in the top ten infected states of the US (see Table 3). In doing so, the study uses ground-level Ozone pollution ($O_3$) as a measure of air pollution and the number of confirmed COVID-19 cases as a proxy of COVID-19 by following Yongjian et al. (2020). The daily mean data of $O_3$ pollution (ppm) is sourced from EPA, while the number of confirmed COVID-19 cases has taken from the official website of US facts. The data of each series has transformed in log return that includes 133 observations starting from February 29, 2020 to July 10, 2020. Table 3 reports descriptive statistics of both series, where New York shows the highest number in COVID-19 infected cases, while California shows lowest. Similarly, Georgia corresponds to the highest $O_3$ emissions while Arizona shows the lowest level. The Jarque-Bera (JB) test statistics are significant at a 1% level of significance, which exhibits that COVID-19 infected cases and $O_3$ pollution are not normally distributed in any of the states under consideration. Similarly, from Table 4, the non-linearity among series is further endorsed by BDS (1996) test, where the null hypothesis of non-linearity is accepted in both series across all States. Based on the JB test and BDS test of nonlinearity, it is evident that both variables having a nonlinearity in all states, therefore, the estimations of quantiles are recommended following (Shahbaz et al., 2018; Mishra et al., 2019; Sharif et al., 2019a; Sharif et al. 2019b, 2020; Chang et al., 2020; Arain et al., 2020).

In the presence of non-normality of data and non-linearity, quantile on quantile regression is the most appropriate technique which produced robust estimates whilst allowing basic data distribution assumption. Therefore, the present research employs quantile-on-quantile (QQ) approach presented by Sim and Zhou (2015), to scrutinize the asymmetric relation between COVID-19 and air pollution ($O_3$) in top 10 most infected states of US. Shahbaz et al. (2018) argued that the QQ method integrates the features of both quantile regression as well as a non-parametric approach to detect the model’s asymmetric and spatial features over time. The non-parametric quantile regression model applied in the study is shown in the following equation:

$$COVID_{t} = \gamma_s(O_{3t}) + \mu_s$$

$$O_{3t} = \gamma_s(COVID_{t}) + \mu_s$$

where $COVID_{t}$ represent the number of confirmed COVID-19 cases, $O_3$ denotes country’s air pollution (ozone $O_3$), $t$ denotes time, the conditional $s$th quantile distribution of $O_3$ is denoted by $\gamma_s$, the quantile error term, whose conditional $s$th quantile is equivalent to 0 is designated by $\mu_s$. $\gamma_s(\cdot)$ is an unidentified function as no former evidence on inter-linkages between $O_3$ pollution and COVID-19 is available. In non-parametric QQ estimations, the bandwidth (k) selection is imperative as it regulates the estimated coefficients’ smoothness. We have used 5% ($h = 0.05$) bandwidth of density function for optimal parameters by following Sim and Zhou (2015). The QQ regression offers detailed information on how different quantiles of COVID-19 influence different
quantiles of \(O_3\) pollution and in turn how \(O_3\) pollution responds to COVID-19 across diverse quantiles by giving a more reliable visual representation of desired variables. Besides, QQ approach has a vital advantage of elasticity as it assesses the valuable dependence between \(O_3\) pollution and COVID-19 in the regions that are not formerly presumed.

4. Results and discussion

Fig. 1 represents the visual depiction of QQ estimates. In the case of New York, visual 1 depicts a strong negative influence of COVID-19 on air pollution in the grid of middle to higher (0.4–0.8) quantiles of COVID-19. This effect is persistent across all corresponding qualities of air pollution. Interestingly, extreme lower and extreme higher quantiles of COVID-19 shows the minimal effect on reducing air pollution yet negative. These results indicate that at the initial level of pandemic the pollution is not substantially reduced, however, with the increase in COVID-19 intensity (cases) the pollution-reducing effect of COVID-19 becomes stronger. There is theoretical and practical plausibility of the results, as at the initial stage of COVID-19 the businesses were usually operating, however, after severity in infected cases in the start of April 2020, the government decided to shut down or early closure of several businesses including schools, transportation, manufacturing, and industrial units, that leads to lower energy and fuel consumption and subsequent air pollution (Berman and Ebisu, 2020). After the peak stage of the pandemic, the lower negative coefficient at extreme high quantile corresponds to the current situation, where the government beginning to lift lockdown, people are moving towards their routine life and businesses. The visuals of California and Florida represent a strong negative influence of COVID-19 on air pollution in the grid of lower to higher (0.2–0.8) quantiles, and medium to higher (0.6–0.8) quantiles, respectively.

The patterns of Texas is also not entirely different, where extreme higher quantiles (0.8–0.9) show the highest negative effect of COVID-19 on air pollution, however, this effect turns week across lower quantiles of air quality. Though all states produce the negative effect of COVID-19 on environmental pollution, however, the intensity of this negative effect varies across different quantiles of COVID-19 and air pollution. Conversely, the patterns of New Jersey and Georgia reflect that the negative effect of COVID-19 on air pollution is highest at the lowest (0.2–0.6) quantiles and lowest at highest quantiles (0.8–0.9) of COVID-19. Following a similar pattern, Arizona shows the highest negative effect of COVID-19 on air quality at the lowest quantiles (0.1–0.2) of both COVID-19 and air pollution. This intensity is equally observed from the corresponding quantiles of air pollution. Unlike other states, the graphical depiction of Illinois shows a strong negative effect of COVID-19 on air pollution from lower to higher (0.2–0.8) quantiles of COVID-19, however, this high negative effect persist only for lower to medium quantiles (0.2–0.4) of air pollution, after which it become less pronounce (0.6–0.8 quantiles). Lastly, Massachusetts shows a moderate negative effect of COVID-19 on air pollution from medium to higher (0.4–0.9) quantiles of COVID-19 yet this negative effect turns weaker across corresponding higher quantiles of air pollution (0.6–0.9).
Interestingly, lower quantiles of COVID-19 and air pollution (0.1–0.3) reflect the highest pollution-reducing effect of COVID-19. Conversely, Pennsylvania exhibit the negative effect of COVID-19 on air pollution only at medium to higher quantiles (0.5–0.9) of COVID-19, while lower quantiles of COVID-19 and air pollution shows a positive impact of COVID-19 on air pollution, indicating that at the initial level of COVID-19 chaotic movement of people and transport increase air pollution. The pollution-reducing effect of COVID-19 is mainly attributed to partial or complete lockdown (see Table 1 for detail), lower human and industrial activity, that ultimately reduces fuel and energy consumption, and resultantly lower air pollution across all US states. These results are consistent with a major strand of literature (Shrestha et al., 2020; Zhang et al., 2020; Bashir et al., 2020).

Now moving to the flip side of the relationship between air pollution and COVID-19, which produces diverse outcomes across the grid of quantiles. While examining the influence of air pollution on COVID-19 in New York, Florida, and Georgia, we observe a weak positive effect of air pollution on COVID-19 mainly in the area of middle to higher (0.4–0.9) quantiles of air pollution. This weak positive effect is equally spread over the corresponding quantiles of COVID-19 except for lower to medium (0.2–0.6) quantiles in Georgia, where a strongly negative effect holds. The lower quantiles of air pollution (0.1–0.3) correspond to relatively higher values of COVID-19 cases. Although Pennsylvania and California show a strong positive influence of air pollution on COVID-19 across medium to higher (0.5–0.8) quantiles, however, this positive effect gradually decreases when moved from medium to lower quantiles (0.4–0.2) of air pollution. In the case of Texas and Illinois, the influence of air pollution on COVID-19 is highest at lower quantiles (0.1–0.3) of air pollution and COVID-19. This positive effect is weaker at the highest (0.8–0.9) quantiles of COVID-19 against all quantiles of air pollution in Texas.

Unlike previous explanation, where the effect of air pollution on COVID-19 varied across quantiles but remains positive, the influence of air pollution on COVID-19 is strongly positive from medium to higher (0.4–0.8) quantiles in New Jersey, from lower to medium quantiles (0.1–0.5) in Arizona, and turns negative for extreme high quantile of COVID-19 in New Jersey and extreme high quantile (0.8–0.9) of air pollution in Arizona. In Massachusetts, air pollution strongly influences COVID-19 in higher quantiles (0.8–0.9) of air pollution, while this effect turns negative from medium to lower quantiles (0.4–0.1). This effect is equally distributed across the quantiles grid of COVID-19. This section of the findings aligns with recent literature and scientific outcomes, which claims that in the presence of ozone pollution, when inhaled, ozone can damage the lungs, caused chest pain, shortness of breath, coughing, and throat irritation. It may also worsen chronic respiratory diseases such as asthma as well as compromise the ability of the body to fight respiratory infections (Martelletti and Martelletti, 2020; US EPA, 2020a; 1996b). These symptoms are highly linked to COVID-19 (Manisalidis et al., 2020); thus, the overall positive effect attribute that in the presence of higher air pollution (Ozone O<sub>3</sub>), the tendency and vulnerability of COVID-19 cases increases (Wu et al., 2020a, 2020b; Cole et al., 2020).

Fig. 1. (continued).
5. Conclusion and policy recommendation

This paper concurrently examines the effect of COVID-19 on air pollution and the effects of air pollution on COVID-19 in the topmost infected states of the US. The results of QQ approach confirm overall dependence and asymmetricity between COVID-19 and air pollution. In this study, air pollution is measured as ground-level ozone $O_3$ pollution, which is the most relevant pollution that increases the vulnerability of chronic respiratory diseases such as COVID-19. The result confirms that an increasing number of COVID-19 cases temporarily reduce $O_3$ pollution almost in all US states due to the slow down of economic activities and partial/complete lockdown in US states. On the flip side, higher environmental pollution leads to a higher number of COVID-19 cases amid raising respiratory disorder and weakening the immune system of the inhabitant lived in highly polluted areas. The intensity of these negative and positive effects on the environment and human lives are diverse across quantiles, which are mainly attributed to the different demographic characteristics, distinct social distancing, and lockdown measures taken by the US states.

In case of New York/Massachusetts, the pollution-reducing effect of COVID-19 is highest at the range of middle to higher quantiles (0.4–0.8) of COVID-19, while California/Illinois, Florida, and Texas exhibit a strong negative influence of COVID-19 on air pollution in the grid of lower to higher (0.2–0.8) quantities, medium to higher (0.6–0.8) quantiles, and extreme higher quantiles (0.8–0.9), respectively. These results indicate that at the peak of COVID-19 intensity (higher quantiles), the pollution reduction effect of COVID-19 is highest, which is mainly attributed to strict lockdown measures taken by respective states.

Contrarily, New Jersey, Georgia, and Arizona represent the highest negative effect of COVID-19 on air pollution at the lower (0.2–0.6) quantiles and lowest at highest quantiles (0.8–0.9) of COVID-19. These results indicate that at a mid-high level of COVID-19 intensity, the pollution-reduction effects of COVID-19 were higher and vice versa. The asymmetrical link between COVID-19 and pollution is primarily recognized with the depth and width of different lockdown measures (see Table 1 for detail).

On the other hand, New York, Florida, and Georgia show a moderate positive influence of air pollution on the intensity of COVID-19 cases at the middle to higher (0.4–0.9) quantiles of air pollution. In the case of Pennsylvania and California, a strong positive influence of air pollution on COVID-19 cases is observed across medium to higher (0.5–0.8) quantiles. However, the intensity of COVID-19 cases gradually declines with the reduction in air pollution from higher to lower quantiles (0.4–0.2). These results imply that higher levels (higher quantiles) of pollution corresponds to a higher number of COVID-19, while a lower level of pollution is associated with a lower number of COVID-19 cases. From a policy perspective, we observed that there is a murky relationship between air pollution and COVID-19 spread, which may mean that tackling air pollution will be a crucial part of easing lockdown to encounter socio-economic challenges that emerged from halted economic activities.

The results imply that environmental pollution is a man-made phenomenon and people are harming the natural environment in which they live. For this reason, perhaps, COVID-19 will take its place as a pandemic that increased human awareness about environmental issues. However, the impacts and consequences of the coronavirus pandemic on...
our lives, societies, and economies are more perilous such a sharp rise in global unemployment distorting our socio-economic balances. The maintainers and creation of jobs in a sustainable manner and improvement in healthcare systems are imperative measures to be taken. In doing so, new engagements from the government to improve climate conditions could be found helpful in generating green jobs and put the foundation for sustainable recovery. Many countries, like Pakistan and Nepal, have initiated such projects that can help the government’s Green Wagers Initiative through which green jobs and fiscal stimulus programs could be instigated through tree plantations and ecosystem restoration. Moreover, enhanced focus on forestry projects under the current situation can also assist the forest community to augment livelihoods through the sustainable harvest of timber and other products. Also, developing sustainable infrastructure over degraded public areas could assist in creating green employment and augment environmental resilience.

Credit author statement

Asif Razzaq: Conceptualization, Writing - original draft, Arshian Sharif: Supervision; Methodology and Analysis. Noshaba Aziz: Writing - original draft & Editing, Muhammad Irfan: Writing - review & editing, Kittiak Jermsittiparsert: Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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