Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Can commercial trade represent the main indicator of the COVID-19 diffusion due to human-to-human interactions? A comparative analysis between Italy, France, and Spain

E. Bontempi a,*, M. Coccia b, S. Vergalli c, A. Zanoletti a

a INSTM and Chemistry for Technologies Laboratory, University of Brescia, Via Branze 38, 25123, Brescia, Italy
b CNR – National Research Council of Italy Via Real Collegio, N. 30 (Collegio Carlo Alberto), 10024, Moncalieri, TO, Italy
c Fondazione Eni Enrico Mattei (FEEM) and Department of Economics and Management, University of Brescia, Via San Faustino, 74/b, Brescia, Italy

ARTICLE INFO

Keywords:
COVID-19
Coronavirus
SARS-CoV-2 spread
Pandemic crisis
Import-export
Population density
Fatality rate
Public health
Gross domestic product (GDP)

ABSTRACT

The main goal of this study is to analyze the relation between commercial trade and pandemic severity in society, in order to support new hypotheses which can explain transmission dynamics of COVID-19, as well as promote policy responses to cope with future epidemics similar to COVID-19. This study considers the role of trade in the dynamics of pandemic diffusion, within and between countries, which has not been investigated yet in this emerging field of research. We focus on three large countries in Europe: Italy, France, and Spain. The analysis is performed at regional level (involving in total 52 European regions). Results suggest that the association between trade and pandemic severity seems to be supported by empirical evidence, making it possible to introduce new hypotheses for explaining transmission dynamics of COVID-19 within and between countries. In particular, international trade data is supposed to be used as a comprehensive indicator accounting for population density, economic dynamism, and human mobility. The statistical analyses, also in a multivariate context, strongly support this hypothesis and suggest that crisis management has to focus in the very first place on infections occurring outside the national boundaries, in order to cope with pandemic threat of new waves of COVID-19 and future similar epidemics/pandemics.

1. Introduction

Understanding the determinants that contributed to the initial diffusion of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), the novel virus that causes coronavirus disease 2019 (COVID-19), is critical for different reasons, such as to provide suitable scientific responses to the still-controversial proposed mechanism of airborne virus transmission and to support appropriate policy responses to cope with this environmental threat to the health of the world’s population and in general to our socioeconomic systems (Coccia, 2020, 2021). Indeed, even though literature has already provided evidence that the aerosol generated by infected people can contribute to the indoor spread of SARS-CoV-2, there is some uncertainty concerning outdoor airborne transmission, also due to the possibility of bioaerosol travelling for several meters (Bontempi, 2020; Bontempi et al., 2020).

In this context, several studies postulated a direct correlation between air pollution and the virus spread (defined as environment-to-human pollution or air pollution to human transmission by Coccia, 2020), suggesting that mechanisms other than human-to-human transmission have an active role in the COVID-19 diffusion (Chirizzi et al., 2021; Coccia, 2021; Copat et al., 2020). Other studies (Wang et al., 2020; Bontempi, 2020b) recognized the fundamental role of the human-to-human interactions, supported by an increased international exchange in the COVID-19 infection global spread, that happened at an impressive and unexpected rate (Anand et al., 2021). For example, human mobility was recognized to be the source of the early epidemic growth rate in China (Kraemer et al., 2020). Menkir et al. (2021) argued that predictions of international outbreaks were mainly based on imported cases from Wuhan (China), potentially missing imports from other cities. The model used by these scholars suggests that some COVID-19 cases were imported to African destinations and 90% of imported cases arrived between the 17th of January and the 7th of February 2020, before the first case detections. In short, the dynamic role of source locations can support surveillance and response efforts.

* Corresponding author.
E-mail address: elza.bontempi@unibs.it (E. Bontempi).

https://doi.org/10.1016/j.envres.2021.111529
Received 21 February 2021; Received in revised form 15 May 2021; Accepted 10 June 2021
Available online 18 June 2021
0013-9351/© 2021 Elsevier Inc. All rights reserved.
The spread of COVID-19 has been very difficult to study partly because of lockdown periods that have interrupted and changed its dynamics (Cocker et al., 2020; De Angelis et al., 2021). Coccia (2021) explains how COVID-19 was transmitted so rapidly in northern Italy, analyzing the underlying relationships between infected people and environmental, demographic, and geographical factors that influenced its spread. In particular, cities with little wind, high humidity and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — seemed to have higher numbers of COVID-19 infected individuals and deaths (cf. Coccia, 2020). Ahmed et al. (2020) focus on different demographic, socioeconomic and lifestyle health factors in countries, to explain the variety of COVID-19 effects in societies. The risk of vulnerability of cities to future epidemics and pandemics similar to COVID-19 may be caused by some factors, such as (Coccia, 2020) high air pollution, little wind, high density of population and social interaction, and previous incidence of lung and bronchi cancer.

However, a suitable way to consider the human-to-human interactions due to people mobility (accounting, for example, for exchanges among different countries) is still not considered in the modeling of the different aspects of SARS-CoV-2 diffusion. In particular, detailed analyses of possible global commercial trade scenarios due to the pandemic have been proposed (Guan et al., 2020) but an inverse inspection, investigating the role of commercial trade in the dynamics of pandemic diffusion, within and between countries, being it a comprehensive indicator of population density, economic dynamism and human mobility, has not been explored yet in this emerging field of research. The analysis of past epidemic diffusions shows that viruses diffused faster during economic booms (Adda, 2016). This can be attributed to the increase of people travelling, with consequent increase of interpersonal contacts. Then it becomes possible to use commercial trade as an indicator of people mobility.

In addition to this, over the last couple of centuries, a positive economic growth took place almost all around the world. This process was coupled with a corresponding increase in global trade, with an evolution of the economy toward a global dimension. Today, about one fourth of total global production is exported (The Economy ebook, 2017).

As shown in supporting information S1 (see the Supporting), a strong correlation between economic growth and commercial trade is established: countries with higher rates of GDP growth also tend to have higher rates of growth in trade as a share of output. This allows to suppose that international trade can be considered also an indicator of GDP.

Bontempi (2020b) suggests that a more exhaustive and comprehensive approach to the explanation of transmission dynamics of the COVID-19 can be achieved by considering different parameters that may be not strictly related to sanitary implications. In these topics, there is a possibility to apply a trans-disciplinary approach to analyze such a complex system, which, for its nature, encompasses many factors.

The main goal of this study is to analyze the relation between commercial trade and pandemic severity in society, in order to support new hypotheses which can explain the transmission dynamics of COVID-19, as well as promote policy responses to cope with future epidemics similar to COVID-19.

2. Study design

2.1. Research setting and sample

This study focuses on all the regions of three large countries in Europe: Italy, Spain, and France (totally 52 regions, listed in the Supporting). These three countries have a similar socioeconomic background for appropriate comparative analyses. In particular, considering that these countries have applied similar lockdown policies, the evolution of the local (in all the countries’ regions) transmission can be investigated comparing the available data of their international trade exchanges, just before the pandemic’s outbreak. In particular, this study performs a comparative analysis, using data at regional level, in order to carry out appropriate comparisons of the relation between possible determinants and effects of COVID-19 in society.

2.2. Measures

To account for the SARS-CoV-2 spread differences that can be found in different geographical areas (also of the same country), it is necessary to choose first a suitable indicator. It must be indicative of human-to-human interactions, given the basic recognized mechanism of initial virus diffusion (Ferretti et al., 2020). Then, it must be correlated with the human mobility factor, since the virus requires high levels of humans’ interactions. This measure can be validated by considering different countries. Notably, commercial relationships, related to the globalization of companies’ value chains and markets, are based on persistent mobility patterns across different countries, and, differently from vacation travels, they often need close social interaction among individuals (Bontempi et al., 2020). Hence, they can be considered as the synthetic expression of social relationships, which are created by economic activities, requiring human contacts due to business collaborations. In fact, globalization has been accompanied by a growing share of international trade. The increase of imports of resources is also indicative of increasing living standards (Rodrique, 2020; Oster, 2012) and GDP (see supporting information S1). In addition, recent literature has already proposed a correlation between COVID-19 case incidence and GDP (Aycock, 2021) in several countries, showing that economic development facilitates infectious disease spread, due to advanced transportation system, better domestic and international travel for businesses, and more group activities. In the present study, the indicator selected to be representative of living standard, economic dynamics, and globalization level of a region is the sum of the total amount of import and export international trade (see Fig. 1). These data were collected considering the last reported available international trade data (2019) for each region of Italy, Spain, and France (in total 52).

Concerning the spread of contagion, the reported epidemiological data are generally considered as an approximation, since they may be different in the selected regions. Indeed, the documented and detected infections depend on testing capability (less testing causes a lower reporting of asymptomatic positives, thus leading to under-estimation; cf., Bertuzzo et al., 2020). Also, mortality rates can depend on several factors, such as the criteria used for its evaluation (Giordano et al., 2020) and the stress suffered by healthcare facilities (Bertuzzo et al., 2020). On the contrary, the number of hospitalized patients in Intensive Care Units (ICU) can be assumed to be a strong indicator of pandemic severity.

Fig. 1. Import-export trade data is considered a complex indicator including manifold drivers of human-to-human interactions, responsible of COVID-19 transmission dynamics in geo-economic areas.
being it a suitable parameter also for comparisons between different regions in different countries. Considering the number of hospitalized patients in ICU at the peaks of the contagion makes all the data comparable, also because they do not depend on the local temporal difference of regional virus diffusion.

To systematize, the measures applied in this study, using data at regional level in Italy, France, and Spain (the 52 total regions studied are listed in the Supporting), are the following ones:

- Gross Domestic Product per capita (GDP PC) for all the regions of Italy, France, and Spain (2019 per Italy, 2016 per France, 2018 per Spain; these data are the latest available at regional level). The data were downloaded by the national statistics websites of the three countries considered (Datacomex, 2021) (Lekiosque, 2021) (Istat, 2021).
- 2019 Import and export, total value in Euros (€), for all the regions of Italy, France, and Spain. The data were downloaded by national statistics websites of the three countries considered (Datacomex, 2021) (Lekiosque, 2021) (Istat, 2021).
- ICUs during the 1st peak in April 2020, 2nd peak in November 2020, 3rd peak in January 2021 or thereabouts, for all the regions of Italy, France, and Spain. The data were downloaded by national websites devoted to pandemic data publication (RTVE, 2021) (Cascororonavirus, 2021) (Protezione Civile, 2021).
- Hospitalization of people (included ICUs) during the 1st peak in April 2020, 2nd peak in November 2020, 3rd peak in January 2021 or thereabouts, for all the regions of Italy, France, and Spain. The data were downloaded by national websites devoted to pandemic data publication (RTVE, 2021) (Cascororonavirus, 2021) (Protezione Civile, 2021).
- Confirmed cases during the 1st peak in April 2020, 2nd peak in November 2020, 3rd peak in January 2021 or thereabouts for all the regions of Italy, France, and Spain. The data were downloaded by national websites devoted to pandemic data publication (RTVE, 2021) (Cascororonavirus, 2021) (Protezione Civile, 2021).
- Deaths during the 1st peak in April 2020, 2nd peak in November 2020, 3rd peak in January 2021 or thereabouts for all the regions of Italy, France, and Spain. The data were downloaded by national websites devoted to pandemic data publication (RTVE, 2021) (Cascororonavirus, 2021) (Protezione Civile, 2021).
- Fatality rate (=14 days from ICUs admission) during the 1st peak in April 2020, 2nd peak in November 2020, 3rd peak in January 2021 or thereabouts for all the regions of Italy, France, and Spain. The data were downloaded by national websites devoted to pandemic data publication (RTVE, 2021) (Cascororonavirus, 2021) (Protezione Civile, 2021). The lag of about 14 days from initial symptoms to deaths is based on empirical evidence of some studies (Zhang et al., 2020).
- Population density, expressed as the number of people per km² of land area for all the regions of Italy, France, and Spain. The data were downloaded by national websites devoted to population statistic data publication (INE, 2021) (INED, 2021) (Istat, 2021).

2.3. Data analysis procedure

2.3.1. Statistical analyses per country

Comparative analysis is performed investigating the relationships between the studied variables with descriptive statistics (arithmetic mean and standard deviation) within countries, using regional data, and with non-parametric correlation Kendall’s tau-b considering the small sample within countries with regional data (Supporting for regions studied here). Kendall’s tau-b (τb) correlation coefficient (Kendall’s tau-b) is a nonparametric measure of the strength and direction of association that exists between two variables, alternative to the Pearson’s correlation when data has failed one or more of the assumptions of this test.

These two assumptions of Kendall’s tau-b are:

1. Variables are measured on a continuous scale.
2. Kendall’s tau-b determines whether there is a monotonic relationship between two variables.

To confirm these results, the Pearson correlation is used as well. Finally, to analyze the effects of the COVID-pandemic across regions, the number of hospitalized patients (log scale) in Intensive Care Units (ICU) at the peaks of the contagious curves in France, Italy, and Spain regions (data refer to 13th April for France and Spain’ and to 1st April for Italy’) is studied as a function of the sum of total amount of import and export international trade (data are reported in €, in log. Scale for each region).

2.3.2. Statistical analyses using regional aggregated data for the three countries under study

This statistical analysis considers all provinces of three countries (Italy, France, and Spain) under study with N = 52 regions. Bivariate Pearson correlations were used to verify relationships between variables, with the degree of association determined by the coefficient of correlation. One-tailed tests of significance for correlation were computed to consider the associations between variables in the most recent year available in the databases.

The correlation is also performed using as control variables the density of population (inhabitants per km²) and GDP PC, to verify if the association between variables is consistent, removing the factors of other variables.

Multivariate analysis is performed with multiple regression with the following models, specified as follows:

\[
\log y_t = \alpha + \beta_1 \log x_1, t - 1 + \beta_2 \log x_2, t - 1 + \beta_3 \log x_3, t - 1 + \beta_4 \log x_4, t - 1 + \mu
\]

where:

- \( y \) = dependent variable (ICUs, Hospitalization, Confirmed cases) in April 2020, November 2020, and January 2021
- \( x_1 \) = explanatory variables of total Import -Export
- \( x_2 \) = explanatory variables of density of population per (inhabitants per km²)
- \( x_3 \) = explanatory variables of Gross Domestic Product per capita
- \( x_4 \) = explanatory variables of Interaction density of population × Gross Domestic Product per capita
- \( \alpha \) is a constant; \( \beta_i \) = coefficient of regression \( i = 1, 2, 3, 4; t = \) time; \( \mu \) = error term.

Statistical analyses are performed with the Statistics Software SPSS® version 26.

3. Results and discussion

3.1. Results for Italy, France and Spain

Table 1 shows the descriptive statistic data for all the countries considered, reported as mean values, at the regional basis. Then, Table 1 allows to have a global vision of the data for all the countries. It shows that the volume of export and import is high in Italy and very high in France. The highest density of population in Italy is 182.10 inhabitants per km², whereas in France is about 173, and in Spain 170. France and Spain have total confirmed cases, hospitalization and ICU admissions during the first, second and third peaks of COVID-19 pandemic always higher than Italy. The ratio between total cases and population confirms roughly these results. The total hospitalization divided by total cases in the first peak is higher in France and Spain, while in the second peak it’s higher in Italy and in the third peak higher in Spain. Finally, fatality rate shows that Italy tends to have higher values in all of the three peaks.

Table 2 presents Kendall’s τ_b correlation coefficient, \( \tau_b \), which shows the association between the total value of import - export and confirmed cases in the first, second and third peaks (≥0.75, p-value < .01). The magnitude of the Kendall’s τ_b correlation coefficient, \( \tau_b \),
the higher level of Kendall's tau-b correlation coefficient, \( \tau \), when using the variable of total import and export. The international trade data and ICU hospitalized patients for all Italy, Spain, and France regions (concerning first wave peak) are reported in Fig. 2. This Figure allows a visual inspection of data, clearly highlighting a correlation, that is quantified in Table 5.

In particular, Table 5, reports the Pearson correlation concerning the first and second pandemic peaks for all the countries considered. In addition, Table 5 also reports the Pearson correlation between the ICU hospitalized patients and the density of population of the corresponding regions.

It is very interesting to highlight that the results show a strong positive correlation between the international trade data and the ICU hospitalized patients, for both pandemic peaks for all countries. A correlation between ICU hospitalized patients and the density of population is also evident but only for Italy and France. The increase in population density is expected to raise the possibilities of social contacts, then the virus spread. Instead, surprisingly, the correlation is already established considering international trade. The lack of correlation between pandemic data and population density considering the Spanish regions, highlights that virus diffusion mechanism is very complex, because social interactions can be higher in some regions, even if with reduced people density, in comparison to other regions with higher density.
population density. Then, this parameter can be unsuitable to model pandemic diffusion. On the contrary, international trade data results more robust. This is evident from the data inspection (see Fig. 2) and analysis (see Tables 4 and 5).

Fig. 2 allows to present a new picture of the pandemic in the EU countries considered, enabling us to learn a new lesson about SARS-CoV-2 diffusion in the society. To the best of our knowledge, the approach is unique not only for the data that are reported, but also in pooling and comparing information from multiple regions of different countries at once. In particular, despite the role of international trade has already been proposed (Bontempi, 2020b; Bontempi et al., 2020), the already published data only concerned Italian regions and their import and export trade data with China. In the present case, the analysis was extended to all the regions of other countries (France and Spain) and to data concerning the total international trade of all the regions (i.e. with all their foreign partners).

In conclusion, Fig. 2 shows that the evolution of the infection must be inspected by a multilevel analysis, highlighting the potential of a transdisciplinary vision, crossing the disciplines’ borders to better focus on what emerges from the data (Rigolot, 2020). What clearly appears is that the complexity of such a system cannot be described only considering a strict virology perspective, but it requires the involvement of global connectivity of cultural, social, and economic systems, with the possibility of different variables interdependence (Bontempi, 2021).

3.2. Results of aggregated data using all regions of Italy, France and Spain

Table 6 shows partial correlation, controlling for the density of population and GDP PC. Results reveal that the association between total import and export and ICUs, hospitalization and confirmed cases is

| Table 3 | Correlation Kendall’s τb, using hospitalization. |
|---------|-----------------------------------------------|
|         | Italy                                       | N = 20 | Density of population | Hospitalization 1 peak | Hospitalization 2 peak | Hospitalization 3 peak |
| Import  | Correlation Coefficient                     | 1.000  | .295                  | .599**                  | .737**                  | .768**                  | .832**                  |
| Export  | Correlation Coefficient                     | .295†  | 1.000                 | .143                    | .411**                  | .253                    | .232                    |
| GDP PC  | Correlation Coefficient                     | .599** | .143                  | 1.000                   | .589**                  | .642**                  | .684**                  |
| Density | Correlation Coefficient                     | .599** | .143                  | 1.000                   | .589**                  | .642**                  | .684**                  |
| population | Correlation Coefficient | .513** | .487†                 | .103                    | .205                    | .231                    | .231                    |
| France  | Correlation Coefficient                     | .298†  | .006                  | .100                    | .193                    | .158                    | .123                    |
| N = 19  | Correlation Coefficient                     | .041   | .006                  | .100                    | .193                    | .158                    | .123                    |

*Correlation is significant at the 0.05 level (1-tailed). **Correlation is significant at the 0.01 level (1-tailed).

| Table 4 | Correlation Kendall’s τb, using ICUs admission. |
|---------|-----------------------------------------------|
|         | Italy                                       | N = 20 | Density of population | ICUs Admission 1 peak | ICUs Admission 2 peak | ICUs Admission 3 peak |
| Import  | Correlation Coefficient                     | 1.000  | .295                  | .599**                  | .723**                  | .758**                  | .768**                  |
| Export  | Correlation Coefficient                     | .295†  | 1.000                 | .143                    | .406**                  | .242                    | .253                    |
| GDP PC  | Correlation Coefficient                     | .599** | .143                  | 1.000                   | .553**                  | .610**                  | .706**                  |
| France  | Correlation Coefficient                     | .256   | .462                  | .744**                  | .684**                  | .692**                  |
| N = 13  | Correlation Coefficient                     | .041   | .006                  | .100                    | .018                    | .106                    | .106                    |
| Spain   | Correlation Coefficient                     | .298†  | .006                  | .100                    | .027                    | .027                    | .129                    |

*Correlation is significant at the 0.05 level (1-tailed). **Correlation is significant at the 0.01 level (1-tailed).
The first coefficient of regression in the model indicates that an increase in import and export (controlling for the density of population, GDP PC and interaction variable), it increases (Table 7):

- the expected ICUs in November 2020 by 0.67% (p-value < .001)
- the expected ICUs in January 2021 by 0.72% (p-value < .001)
- the expected Hospitalization in April 2020 by 0.71% (p-value < .001)
- the expected Hospitalization in November 2020 by 0.69% (p-value < .001)
- the expected Hospitalization in January 2021 by 0.76% (p-value < .001)
- the expected Confirmed cases in April 2020 by 0.62% (p-value < .001)
- the expected Confirmed cases in November 2020 by 0.68% (p-value < .001)
- the expected Confirmed cases in January 2021 by 0.71% (p-value < .001)

The coefficient $R^2$ in Table 7 indicates that about 69–90% of the variables of the health of population can be attributed (linearly) to total import and export (controlling for the density of population, GDP PC and interaction variable), suggesting a consistent and robustness of the model in a multivariate context.

4. Concluding remarks and future perspectives

The association between commercial trade and pandemic severity that seems to be established in Fig. 2 as well as statistical analyses of data correlation and regression can support new conclusions and/or new hypotheses about the pandemic diffusion and data modeling, needing a trans-disciplinary level of analysis.

First, analyzing the number of hospitalized patients in ICU versus a non-conventional reference indicator makes it possible to deduce that the severity of the SARS-CoV-2 infection was actually comparable in those regions that are most active in the commercial activities are generally the richest areas, with an expected higher population mobility, economic dynamism, and more group activities. These considerations allow justifying the choice of commercial trade as a variable, accounting for several determinants of virus diffusion (see Fig. 1), due to human-to-human interactions (cf., Chang et al., 2020; Coccia, 2021a). This...
analysis shows that regions with higher international trade activities (that are representative of living standard, economic dynamics, and globalization level) are more susceptible to be in contact with foreign populations, with an increased risk to import the virus in their communities and spread the diffusion. This is in line with studies reported by Li et al. (2020) that estimated how a large number of undocumented infections originated from China, before travel restrictions, was the source of fast spreading of SARS-CoV-2 around the world. In particular, accelerating events or situations are expected to occur with higher probability in most rich (productive) areas, thus justifying a different growth of the infection rate, also starting from local differences in the origins (Adam et al., 2020).

Another implication regarding the reported data is that globalization appears to be a problem for other future pandemic events. It is evident that, also considering a single country, regions with limited international relationships result less exposed to the virus spread and may turn out to be protected in the eventual condition of a possible undetected infection. The monotone trend of data shown in Fig. 2 may also allow estimating the regions that are more (or less) susceptible to contagious diffusion, identifying and proposing suitable future action strategies.

Hence, statistical analyses strongly suggest that crisis management has to focus on infections occurring from outside the national boundaries, before relaxing foreign mobility limitations (Bertuzzo et al., 2020). The statistical evidence in this study is based on the relation of association between the variables under study, rather than a relation of dependence, because of manifold confounding factors that influence these variables.

Overall, then, this study has investigated the possibility to introduce only a variable to model the pandemic diffusion, due to human-to-human interactions. Preliminary data analysis involving all the Italian 107 provinces is in accord with this study (Bontempi et al., 2021). However, some other critical variables may be needed for more detailed research of other factors associated with the spread of novel infectious diseases, such as environmental factors (temperature, humidity, wind

| Control Variables, Log GDP PC and Population Density | Log Import Export | Log ICUs April 2020 | Log ICUs November 2020 | Log Hosped April, June 2020 | Log Hosped November 2020 | Log Hosped January 2021 | Log Confirmed cases April, June 2020 | Log Confirmed cases November 2020 | Log Confirmed cases January 2021 |
|------------------------------------------------------|-------------------|---------------------|------------------------|--------------------------|------------------------|----------------------|-------------------------------|-------------------------------|-------------------------------|
| Log Import Export                                    | 1.000             | .873                | .927                   | .849                     | .786                   | .912                 | .919                          | .781                          | .921                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log ICUs April 2020                                  | .873              | 1.000               | .885                   | .914                     | .950                   | .846                 | .911                          | .942                          | .922                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log ICUs November 2020                               | .927              | .885                | 1.000                  | .880                     | .797                   | .978                 | .947                          | .778                          | .962                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log ICUs January 2021                                | .849              | .914                | .880                   | 1.000                    | .884                   | .849                 | .962                          | .871                          | .902                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log Hosped April, June 2020                          | .786              | .950                | .797                   | .884                     | 1.000                  | .776                 | .863                          | .979                          | .859                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log Hosped November 2020                             | .912              | .846                | .978                   | .849                     | .776                   | 1.000                | .937                          | .755                          | .946                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log Hosped January 2021                              | .919              | .911                | .947                   | .962                     | .863                   | .937                 | 1.000                         | .845                          | .945                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log Confirmed cases April, June 2020                | .781              | .942                | .778                   | .871                     | .979                   | .755                 | .845                          | 1.000                         | .839                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log Confirmed cases November 2020                   | .921              | .922                | .962                   | .902                     | .859                   | .946                 | .945                          | .839                          | 1.000                         |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |
| Log Confirmed cases January 2021                    | .939              | .923                | .960                   | .936                     | .864                   | .949                 | .980                          | .846                          | .981                          |
| Significance (2-tailed)                              | .001              | .001                | .001                   | .001                     | .001                   | .001                 | .001                          | .001                          | .001                          |

Note: df = 48.
Table 7

Multivariate regression analysis for aggregated data, including all regions of Italy, France and Spain.

|                     | LogICUs April 2020 | LogICUs November 2020 | LogICUs January 2021 | LogHosped April, June 2020 | LogHosped November 2020 | LogHosped January 2021 | Log Confirmed cases April, June 2020 | Log Confirmed cases November 2020 | Log Confirmed cases January 2021 |
|---------------------|---------------------|-----------------------|----------------------|---------------------------|-------------------------|------------------------|-------------------------------------|-----------------------------------|----------------------------------|
| Constant α          | –11.821             | –6982                 | –2.483               | –7.859                    | –8.014                  | –9.09                  | –6.320                              | –3.621                            | –193                            |
| Coefficient β1 Import-Export | .691               | .0670                 | .721                 | .706                      | .683                    | .764                   | .616                               | .682                              | .709                            |
| Coefficient β2 Density Population | –.089              | .0043                 | .112                 | –1.30                     | .058                    | .021                   | –.066                              | .057                              | .064                            |
| Coefficient β3 GDP PC | .080                | –.043                 | –.1039               | –.145                     | –.169                   | –1.041                 | .007                               | –.212                             | –.577                           |
| Coefficient β4 INT Density | 6.06E-015           | 0.000                 | 2.53E-015            | 8.15E-015                 | 1.73E-015               | 2.79E-015              | 7.17E-015                          | 2.81E-015                         | 2.17E-015                      |
| R²                  | .82                 | .88                   | .73                  | .70                       | .86                     | .86                    | .69                                | .87                               | .90                             |
| (St. Err. of Estimate) | .64                  | .47                   | .75                  | .95                       | .51                     | .54                    | .84                               | .48                               | .43                             |
| F-test              | 54.58               | 88.32                 | 32.41                | 26.88                     | 69.86                   | 69.61                  | 26.65                              | 81.05                             | 100.17                          |

Note: log Scale; Predictors: (Constant), Import Export, Density Population (inhabitants per km²), GDP PC, INT=Interaction (Density Pop × Import-Export).

p-value: < .001
p-value: < .01
p-value: < .05

speed, etc., cf., Coccia, 2021b). To conclude, this study is a beginning of a new research investigation field, based on the proposed data, to identify new approaches and sources (for example additional parameters to include in the models) and open challenges for further works, based on a trans-disciplinary path, able to cross the disciplines’ border to better eviscerate the complexity of a pandemic.

Authors contribution

E. Bontempi: Conceptualization and conceiving the original idea, draft preparation and writing. M. Coccia: Statistical analysis, draft preparation and writing. A. Zanotti: Literature survey/mining, Figure designing. S. Vergalli: Critical Review and Editing/Proofreading the manuscript.

Declaration of competing interest

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

Acknowledgments

We thank Mr. Diego Margon from National Research Council of Italy, Dr. Ilenia Romani from FEEM, and Prof. Flaminio Squazzoni from University of Milan for the helpful research assistance in this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.111529.

References

Adam, D.C., Wu, P., Wong, J.Y., et al., 2020. Clustering and superspreading potential of SARS-CoV-2 infections in Hong Kong. Nat. Med. 26, 1714–1719. https://doi.org/10.1038/s41591-020-1092-z.

Adda, J., 2016. Economic activity and the spread of viral diseases: Evidence from high frequency data. Q. J. Econ. 131, 891–941. https://doi.org/10.1093/qje/qjw005.

Ahmed, A., Haque, T., Rahman, M.M., 2020. Lifestyle acquired immunity, decentralized intelligent infrastructures, and revised healthcare expenditures may limit pandemic catastrophe: a lesson from COVID-19. Frontiers in Public Health 8, 566114.

Anand, U., Cabreros, C., Mal, J., Ballesteros, F., Sillanpää, M., Tripathi, V., Bontempi, E., 2021. Novel coronavirus disease 2019 (COVID-19) pandemic: from transmission to control with an interdisciplinary vision. Environ. Res. 2019, 111126. https://doi.org/10.1016/j.envres.2021.111126.

Aycock, L., Chen, X., 2021. Levels of economic development and the spread of coronavirus disease 2019 (COVID-19) in 50 U.S. states and territories and 28 European countries: an association analysis of aggregated data. Global Health Action 14, 24–30. https://doi.org/10.1080/21649355.2021.209639.

Bertuzzo, E., Mari, L., Pasetto, D., et al., 2020. The geography of COVID-19 spread in Italy and implications for the relaxation of confinement measures. Nat. Commun. 11, 4264. https://doi.org/10.1038/s41467-020-18502-0.

Bontempi, E., 2020. Commercial exchanges instead of air pollution as possible origin of COVID-19 initial diffusion phase in Italy: more efforts are necessary to address interdisciplinary research. Environ. Res. 188, 109775. https://doi.org/10.1016/j.envres.2020.109775.

Bontempi, E., 2021. The Europe second wave of COVID-19 infection and the Italy “strange” situation. Environ. Res. 193, 110476. https://doi.org/10.1016/j.envres.2020.110476.

Bontempi, E., Coccia, M., 2021. International trade as critical parameter of COVID-19 spread that outclasses demographic, economic, environmental, and pollution factors. Environ. Res., ER-21-1552. In press.

Bontempi, E., Vergalli, S., Squazzoni, F., 2020. Understanding COVID-19 diffusion requires an interdisciplinary, multi-dimensional approach. Environ. Res. 188 (2020), 109814. https://doi.org/10.1016/j.envres.2020.109814.

Cascovirus, 2021. Statistiques et cas Coronavirus COVID-19 France. https://www.cascovirus.fr/stats/france.

Chang, S., Persson, E., Koh, P.W., et al., 2020. Mobility network models of COVID-19 causal inequities and info reinforcing. Nature. https://doi.org/10.1038/s41550-020-2923-3.

Chirizzi, D., Conte, M., Feltracco, M., Dinoi, A., Gregoris, E., Barbaro, E., La Bella, G., Ciccarese, G., La Saldara, G., Gambaro, A., Contini, D., 2021. SARS-CoV-2 concentrations and virus-laden aerosol size distributions in outdoor air in north and South of Italy. Environ. Int. 146, 106255. https://doi.org/10.1016/j.envint.2020.106255.

Coccia, M., 2020. An index to quantify environmental risk of exposure to future pandemics of the COVID-19 and similar viral agents: theory and Practice. Environ. Res. 191 (December) https://doi.org/10.1016/j.envres.2020.110476. Article number 11155.

Coccia, M., 2021. The role of air pollution (PM and NO2) in COVID-19 spread and related mortality in northern Italy. Environ. Resour. Econ. 76, 611–663. https://doi.org/10.1016/j.scitotenv.2021.145801. (Accessed 12 February 2021).

Cocker, E.S., Cavalli, L., Fabrizi, E., Guastella, G., Lippo, E., Parisi, M.L., Pontarollo, N., Rizzati, M., Varacca, A., Vergalli, S., 2020. The effects of air pollution on COVID-19 related mortality in northern Italy. Environ. Resour. Econ. 76, 611–663. https://doi.org/10.1016/j.scitotenv.2021.145801.
lethality: a systematic review. Environ. Res. 191, 110129. https://doi.org/10.1016/j.envres.2020.110129.

Datacomex, 2021. Estadísticas de comercio exterior de bienes de España y la UE. http://datacomex.comercio.es.

De Angelis, E., Renzetti, S., Volta, M., Donato, F., Calza, S., Placidi, D., Lucchini, R.G., Rota, M., 2021. COVID-19 incidence and mortality in Lombardy, Italy: an ecological study on the role of air pollution, meteorological factors, demographic and socioeconomic variables. Environ. Res. 195, 110777. https://doi.org/10.1016/j.envres.2021.110777.

Ferretti, L., Wymant, C., Kendall, M., Zhao, L., Nurtay, A., Abeler-Dörner, L., Parker, M., Bonsall, D., Fraser, C., 2020. Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. Science 368 (Issue 6491), 489-493. https://doi.org/10.1126/science.abb6936.

Giordano, G., Blanchini, F., Bruno, R., et al., 2020. Modelling the COVID-19 epidemic and implementation of population-wide interventions in Italy. Nat. Med. 26, 855–860. https://doi.org/10.1038/s41591-020-0883-7.

Guan, D., Wang, D., Hallegatte, S., et al., 2020. Global supply-chain effects of COVID-19 control measures. Nat Hum Behav 4, 577–587. https://doi.org/10.1038/s41562-020-0896-8.

INE, 2021. Istituto Nazionale di Statistica. https://www.ine.es/en/index.htm.

INGED, 2021. Istitut National D’étude Démographiques. https://www.ined.fr/en/.

Istat, 2021. Istituto Nazionale di Statistica. https://www.istat.it/.

Kraemer, M.U.G., Yang, C.-H., Gutierrez, B., Pybus, O.G., Scarpino, S.V., 2020. The effect of human mobility and control measures on the COVID-19 epidemic in China. Science 368 (6490), 493–497. https://doi.org/10.1126/science.abb4218.

Lekiosque, 2021. Le chiffre du commerce extérieur. https://lekiosque.finances.gouv.fr/.

Li, R., Pei, S., Chen, B., Yang, W., Shaman, J., 2020. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). Science 368 (6490), 489–493. https://doi.org/10.1126/science.abb2321.

Menkir, T.F., Chin, T., Hay, J.A., et al., 2021. Estimating internationally imported cases during the early COVID-19 pandemic. Nat. Commun. 12 (1), 311.

Oster, E., 2012. Routes of infection: exports and hiv incidence in sub-saharan africa. J. Eur. Econ. Assoc. 10 (Issue 5), 1025–1058. https://doi.org/10.1111/j.1542-4774.2012.01075.x. (Accessed 1 October 2012).

Protezione Civile, 2021. http://www.protezionecivile.gov.it/.

Rigolot, C., 2020. Transdisciplinarity as a discipline and a way of being: complementarities and creative tensions. Humanit Soc Sci Commun 7 (100). https://doi.org/10.1057/s41599-020-00598-5.

Rodrigue, Jean-Paul, 2020. The Geography of Transport Systems – Chapter 7.2 – Globalization and International Trade, fifth ed. Routledge, New York, ISBN 978-0-367-36463-2, p. 456.

RTVE, 2021. La evolución de las UCI en las comunidades autónomas durante la pandemia. https://www.rtve.es/noticias/20200525/uci-coronavirus/2010958.html.

The Economy, 2017. Ebook Developed by CORE Project. https://www.core-econ.org/the-economy/index.html.

Wang, L., Didelot, X., Yang, J., et al., 2020. Inference of person-to-person transmission of COVID-19 reveals hidden super-spreading events during the early outbreak phase. Nat. Commun. 11, 5006. https://doi.org/10.1038/s41467-020-18836-4.

Zhang, B., Zhou, X., Qiu, Y., Song, Y., Feng, F., Feng, J., et al., 2020. Clinical characteristics of 82 cases of death from COVID-19. PloS One 15 (7), e0235458. https://doi.org/10.1371/journal.pone.0235458.