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Applying Space Data to the Analysis of the Economic Impact of Covid-19 Restrictions

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Abstract. The objective of this research is to study the impact of Covid-19 restrictions on the Italian economy based on space data on representative Italian ports. We posit that port activity has a mediation effect on Covid-19 restrictions' impact on the Italian economy. To study port activity we leverage space data and, in particular, earth observation AIS data, which provide different types of information describing a port's activity, such as the number of ships in a port at different points in time and their type. We complement these data with other sources of data, including traffic and mobility data, as well official sources of information on port economics and on the more general trends of the Italian economy. To test our hypotheses, we focus on two large Italian ports, Genoa (Liguria) and Gioia Tauro (Calabria). Our empirical analyses confirm that port activity has a mediation effect on Covid-19 restrictions' impact on the Italian economy. The mediation effect has been found to be partial, as Covid-19 restrictions direct impact on the Italian economy remains significant when port activity is added to the correlation model.

Keywords: *Space Data, Big Data, Data Analytics, Port Activity, Covid-19.*

1 Introduction

The objective of this research is to study the impact of the COVID-19 restrictions on the Italian economy based on space data on representative Italian ports. Starting from the end of 2019, the virus spread all over the world began a pandemic that has led governments to enforce restrictions aimed at ensuring social distancing and, thus, decreasing Covid-19 spread. Italy has been the first country in Europe to be heavily impacted by this pandemic and to impose such restrictions. These restrictions have directly affected certain production activities but have also reduced people's mobility and, thus, changed people's habits, leading to an indirect effect on the Italian economy. These considerations suggest that there is a direct negative effect of Covid-19 restrictions on the Italian economy, but also a more complex indirect effect due to people's changing purchasing behavior.

In this research, we take a step towards understanding these phenomena by studying the activity of representative Italian ports and their main lines of business, namely cruises, transportation of containers and transportation of liquid bulks. Intuitively, changing people's habits may negatively affect certain industries, but may also have a positive effect on other industries providing the goods and services that have become more important to people's lives, such as home appliances and accessories, food, furniture, and home office supplies. Port activity reflects these changes and represents a construct that can help model the economic impact of Covid-19 restrictions.

We posit that port activity has a mediation effect on Covid-19 restrictions' impact on the Italian economy. In the literature, the correlation between port activity and the general trends of a country's economy has been previously found to be significant [1]. In fact, maritime transportation is considered key to the normal functioning of several activities that drive the national and international economy, including, for example, the trade of oil and a variety of raw materials ([2], [3]). Our focus is on the mediation role of port activity between Covid-19 restrictions and Italy's economy. To study port activity we leverage space data and, in particular, earth observation data, which provide different types of information describing a port's activity, such as the number of ships in a port at different points in time, their type, and the level of different pollutants in the atmosphere. We complement these data with other sources of data, including traffic and mobility data, as well as official sources of information on port economics and on the more general trends of the Italian economy.

To test our hypotheses, we have focused on two large Italian ports, Genoa (Liguria) and Gioia Tauro (Calabria), characterized by a balanced mix of the main lines of business of ports. Our empirical analyses confirm that port activity has a mediation effect on Covid-19 restrictions' impact on the Italian economy. The mediation effect has been found to be *partial* [11], as Covid-19 restrictions direct impact on the Italian economy remains significant when port activity is added to the correlation model, as briefly shown in Figure 1. Not all business lines, however, turned out to play the same mediation role, with the transportation of containers showing a more clear mediation effect.

The presentation is organized as follows. The next section provides a short review of the state of the art. Our hypotheses are discussed in Section 3 and Section 4 describes our data and reports on our testing results. Conclusions are finally drawn in Section 5.

2 State of the Art

After over a year from the beginning of the Covid-19 pandemic, several scientific studies have analyzed the economic impact of Covid-19 restrictions and preventive measures ([4], [5]). Restrictions limit people's mobility, as well as their ability to produce and to consume goods and services, resulting into a well-known reduction of the GDP of affected nations. These studies measure various economic indicators to verify the relationship between Covid-19 restrictions and economic losses (or, viceversa, between loosening restrictions and economic growth, [5]). Studies focusing on economic measures of port activity have found that the impact of Covid-19 restrictions on port activity is almost immediate [4]. However, none of these studies addresses the overall

relationship among all three variables, that is Covid-19 restrictions, economic trends and port activity.

Previous studies supporting the macroeconomic relevance of port activity concur that ports play an important role in the economic growth of a country or region [6], [7]. A fundamental observation from these studies is that ports are hubs of the procurement of raw materials, including oil, and, therefore, are beacons of economic trends in the upstream stages of the supply chain in many industries. Before the pandemic, global sea transport was growing steadily [8], positioning ports at the forefront of changes in economic trends and suggesting that port activity can be used as an early predictor of change.

Maritime transport is by nature limited to coastal areas or areas adjacent to waterways, leading to a distinction between two main types of shipping: deep sea shipping (DSS) and short sea shipping (SSS). The difference between DSS and SSS is mainly related to the distance covered by ships and to ship size.

- Deep sea shipping (DSS): It is defined as maritime transport on very long routes, typically across the oceans, from one continent to another one. Ports that are capable to manage DSS are called *gateway ports*. The port of Genoa, one of the focus areas of this study, can manage a multitude of different activities including DSS and is the main Italian gateway port. The port of Genoa, indeed, is the largest Italian port for the number of shipping lines and a fundamental driver of the industrial development of Northern Italy [9].
- Short sea shipping (SSS): It is defined as maritime transport on short distances, typically within the same continent or even within the same country. A typical case of short sea shipping concerns transport in the Mediterranean Sea. One of the fundamental functions of this mode of transport is *trans-shipment*, which consists in redistributing containers from large hubs to smaller national or regional ports. Basically, containers are transferred from a larger ship to a smaller ship, or vice versa. In Italy, trans-shipment traffic is mainly handled by the port of Gioia Tauro, that is the only Italian port entirely dedicated to trans-shipment and the main port in the Mediterranean for SSS [9]. SSS and related trans-shipment activities play an increasingly important role within local economies [8].

The Italian port system is divided into 24 ports managed by port authorities and numerous smaller commercial ports. Despite the presence of a large number of ports, there is a strong concentration in the market, with more than 40% of the total traffic managed by the first 5 national ports, that is Trieste, Genoa, Livorno, Cagliari and Gioia Tauro. We have made a distinction between trans-shipment and gateway ports. The first focus more than 75% of their activity on trans-shipment, such as Gioia Tauro, which leverages on its favorable geographical positioning that allows this port to intercept large trans-oceanic routes, particularly from the Suez Canal towards Europe. Gateway ports, such as Genoa, commonly involve moving containers from one mode of transport to another, for example from ships to trains or trucks. Gateway ports can be considered the continental ports for maritime traffic, which transfer containers from the ship towards the final destination, and vice versa. Genoa and Gioia Tauro are two of the largest Italian ports representing these two models, gateway and trans-shipment, respectively.

3 Research Hypotheses

3.1 Mediation model

Mediation models help understanding the relations among constructs. A statistically significant correlation between two variables indicates a relationship between them that may or may not a causal one. When this relationship is conceptually complex, mediations models help understand why the two variables relate to each other.

Figure 1 shows a general mediation model, with one mediation variable, called M . The mediation variable M helps understand why the dependent Y variable and the independent variable X are correlated. Let us suppose that there exists a statistically significant direct correlation between X and Y , called c in Figure 1. Variable M is supported as a mediation variable if there exists a statistically significant indirect relation between X and Y mediated by M , indicated as the a - b path in Figure 1. Conceptually, this indirect effect corresponds to a situation where X can be supposed to have an effect on M that translates into an effect on Y . This indirect relation represents the (possibly partial) reason why X is correlated with Y , thus (partially) explaining why X and Y relate to each other.

Traditionally, mediation analysis has been formulated, understood, and implemented through the study of linear regressions [11]. Statistically, the mediation effect is *full* if the coefficient of X is significant when testing the direct relation between X and Y , while it is non-significant when M is added to the model (with reference to Figure 2, c is significant and c' is non-significant). The mediation effect is instead *partial* if the coefficient of X is significant when testing the direct relation between X and Y and remains significant when M is added to the model (with reference to Figure 4, both c and c' are significant).

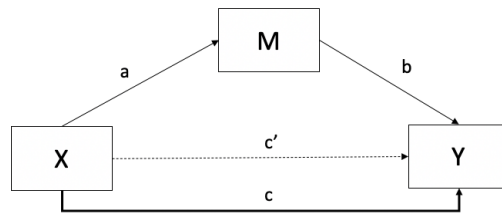


Fig. 1. General mediation model.

3.2 Constructs and Hypotheses

Previous literature has found that a growth in Covid-19 restrictions is associated with both a decrease in macro-economic performance and an overall decrease in port activity (cf. [4], [5]). This is considered a confirmation of the negative impact of Covid-19 restrictions which are deemed to involve a clear slow-down of the economy. The main argument put forward to support this direct relationship between Covid-19 and port activity is that people mobility is limited by restrictions and, with it, their ability to

work and to consume goods and services, with numerous negative consequences on a variety of industries, including tourism, airlines, restaurants, leisure facilities, oil & gas drilling, auto parts and equipment, and fashion (cf. [12]). It is generally believed that releasing restrictions can have the opposite effect, with a consequent economic recovery.

Although we concur with these arguments, we have also observed a growth (as opposed to a decrease) in specific industries during the pandemic. For example, the Italian exports of pharmaceutical, machinery and agri-food industries have grown during the pandemic and the online business has obviously shown a considerable growth (cf. [13]). Our descriptive analytics of port activity show a similar diversity across different lines of business of ports. While the *cruises* and *liquid bulks* lines of business show a sharp decrease in 2020, *containers* (measured in TEUs) have remained steady in Genoa and have significantly increased in Gioia Tauro throughout the pandemic. Figure 2 shows this growth in Gioia Tauro. Gioia Tauro's growth confirms the idea that there exist production activities that do not show a decrease as a consequence of Covid-19 restrictions.

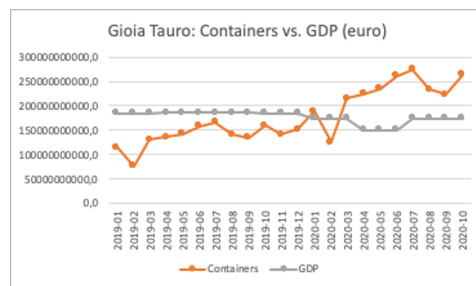


Fig. 2. Port activity of Gioia Tauro vs. Italian GDP (port activity data normalized to GDP scale).

Figure 3 shows the Italian GDP and Covid-19 restrictions trends. Covid-19 restrictions are measured with the Oxford stringency index, see [14]. The source for Italian GDP is the Italian National Statistical Office [15]. The following considerations can be made on the descriptive statistics shown in Figure 3:

- Covid-19 restrictions and Italian GDP are clearly related, but not identical.
- Greater Covid-19 restrictions seem to have an immediate negative effect on GDP.

Overall, Covid-19 restrictions and Italian GDP seem to have different dynamics, with GDP showing greater inertia. Aggregate GDP is the result of many variables, and these slower dynamics can be partly attributed to the fact that GDP is a composite financial index and, as such, is less subject to volatility compared to a single variable such as Covid-19 restrictions. However, the more limited dynamics of GDP are also consistent with the observation that the impact of Covid-19 restrictions is less evident for certain production activities, which, in some cases, have continued to grow as opposed to decreasing.

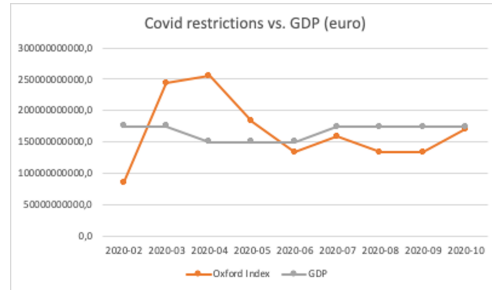


Fig. 3. Covid restrictions in Italy (mean value of Oxford index) vs. Italian GDP (restrictions data normalized to GDP scale).

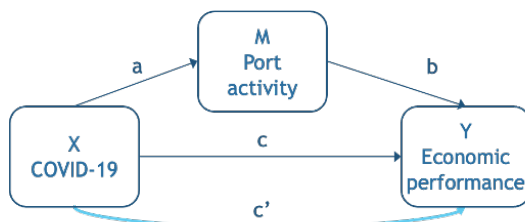
As noted before, Covid-19 has changed the habits of people, but not all industries have been negatively affected. Although restrictions can still have an overall negative impact on economic performance, they may actually increase the consumption of goods and services that have become important to deal with the Covid-19 situation and improve people's new lifestyle, such as home appliances and accessories, food, home office supplies connectivity and online services in general. Port activity reflects these changes and represents a construct that can help understand the relationship between Covid-19 restrictions and the performance of the Italian economy.

These considerations suggest a possible mediation role of port activity, with Covid-19 restrictions impacting on port activity first, with a different intensity depending on the line of business, and hence on GDP. We cannot exclude a direct impact of Covid-19 on GDP, since port activity does not have an equally strong relationship with all production activities, although, as noted in Section 2, it is generally considered an important driver of economic performance. This leads us to the following three hypotheses and to our mediation model shown in Figure 4.

Hypothesis 1 – A growth in Covid-19 restrictions is associated with a decrease in Economic Performance.

Hypothesis 2 – A growth in Covid-19 restrictions is associated with a decrease in Port Activity.

Hypothesis 3 – The relation between Covid-19 restrictions and Economic Performance is mediated by Port Activity.



► Linear regression equations:

- $Y = i_1 + cX + \epsilon$
- $M = i_2 + aX + \epsilon$
- $Y = i_3 + c'X + bM + \epsilon$

Fig. 4. Mediation effect of *Port Activity* on the relationship between *Covid-19* restrictions and *Economic Performance*.

4 Empirical Results

4.1 Testing a Mediation Model: the Causal Steps Approach

We adopt the *causal steps approach* discussed in [11] to test our mediation model. This approach is based on four steps, summarized in Table 1, and applies the OLS (ordinary least squares) method.

Table 1. Testing a mediation model with the causal steps approach [11].

Step	Description	Equations
1	The independent variable X should be significantly correlated with the dependent variable Y, resulting in the significant coefficient c in equation 1 (path c in Figure 4). This step tests whether there is a relationship between X and Y that may be mediated.	(1) $Y = i + cX + \varepsilon$
2	The independent variable X should be significantly correlated with mediation variable M (coefficient a in equation 2 should be significant).	(2) $M = i + aX + \varepsilon$
3	The mediation variable M must be significantly correlated with the dependent variable Y, while controlling for the independent variable X (it is not sufficient to correlate M with Y as they may be correlated because they are both caused by the causal variable X).	(3) $Y = i + c'X + bM + \varepsilon$
4	This last step tests whether the relation between the independent variable X and the dependent variable Y is weaker when the mediating variable M is added to the model. Coefficient c' should be smaller than the coefficient c (i.e., $c - c' > 0$). Mediation is <i>full</i> if c is significant and c' is non-significant, <i>partial</i> if both c and c' are significant.	(4) $Y = i + c'X + bM + \varepsilon$

4.2 Metrics

Covid-19 restrictions

Covid-19 restrictions refers to a broad range of constraints that governments, including the Italian one, have imposed to curb the spread of the virus. We measure these restrictions based on the Oxford stringency index, see [14]. This index is defined to encompass all the restriction measures applied by different countries and is in fact designed to allow for cross-country comparisons. The Oxford index classifies restriction measures along 16 dimensions, of which 8 apply to Italy. These 8 dimensions are reported in Table 2. In this study, we define *Covid-19 restrictions* as an aggregate indicator obtained by summing the values of the Oxford index across the 8 dimensions shown in Table 2, obtaining a metric on an overall 0-23 scale.

Table 2. Definition of the Oxford index [14].

ID	Oxford index dimension name	Value (simplified definition)
C1	School closing	0 – no measures
		1 – recommend closing of selected schools
		2 – require closing of selected schools
C2	Workplace closing	3 – require closing of all schools
		0 – no measures
		1 – recommend closing (or recommend work from home)
C3	Cancel public events	2 – require closing (or work from home) for selected sectors or categories of workers
		0 – no measures
		1 – recommend canceling
C4	Restrictions on gatherings	2 – require canceling
		0 – no measures
		1 – restrictions above 1000 people
		2 – restrictions above 100 people
C5	Close public transport	3 – restrictions above 10 people
		0 – no measures
		1 – recommend closing (or significantly reduce volumes)
		2 – require closing
C6	Stay at home requirements	0 – no measures
		1 – recommend not leaving house
		2 – require not leaving house with exceptions for daily exercise, grocery shopping, and other essential activities
C7	Restrictions on internal movement	3 – require not leaving house with minimal exceptions
		0 – no measures
		1 – recommend no travel
C8	International travel controls	2 – restrict travel
		0 – no measures
		1 – screen arrivals
		2 – quarantine arrivals from some or all regions
		3 – ban arrivals from some regions
		4 – ban on all regions or total border closure

Economic performance

Among the economic performance indicators available from the archive of the Italian statistical office (Istat), we have selected the following [15]:

- 1) the aggregate value of GDP at market prices,
- 2) import/export, and
- 3) household expenditure consumption.

All indicators have been considered at a national Italian level of aggregation.

Port activity

Ports have three main lines of business: passengers, liquid bulks and containers. These three lines of business are defined as follows in this study:

- 1) *Passengers*: this category refers to the people transportation service, including cruises. They are measured as total number of passengers.
- 2) *Liquid bulks*: this category includes the transportation of liquid raw materials, such as mineral and vegetable oils, wine and chemicals handled by special ships called tankers, which are designed to transport or store liquids or gases in bulk. The large majority of liquid bulks consists in crude oil (95% in Genoa port), to the point that major refineries are located near the ports, which offer coastal depots and multi-modal facilities for the distribution of refined products. Liquid bulks are measured in number of oil tankers.
- 3) *Containers*: this category includes the transportation of all solid goods by means of container ships. Solid goods are a very heterogeneous category and, therefore, tons are not considered the most appropriate metric, as the space occupied inside a container is the main business driver. A more appropriate metric is the TEU (Twenty-Foot Equivalent Unit, where 1 TEU corresponds to a 20-foot container) or the total number of container ships. We have found a strong correlation among these three metrics and we measure port activity in this line of business as number of container ships.

Given the different business focus of Genoa and Gioia Tauro, we consider all three metrics for Genoa and containers only for Gioia Tauro. Data on passengers have been collected from [9], while AIS space data have been used to measure the number of oil tankers and container ships [16].

We have defined an aggregate variable called *Composite Port Activity* as the sum across the two ports (Genoa and Gioia Tauro) of the values of passengers, liquid bulks and containers normalized according to a min-max approach.

4.3 Data Sample and Empirical Results

Data have been collected between January 2020 and February 2021. Time is measured in months, as the maximum time granularity available for all metrics. Tests have been performed with the linear regression function of the Python Statsmodels library.

Hypothesis 1 is tested first. Results are reported in Tables 3-6. The correlation between Covid-19 restrictions and GDP at market prices, import and household expenditure consumption is found to be negative and significant. The correlation between Covid-19 restrictions and export is found to be negative, but not significant, as p-value is greater than 0.05. Overall, hypothesis 1 is supported with three out of our four metrics of economic performance. The export variable cannot be considered for the following steps of the causal steps approach (steps 3 and 4 in Table 1).

Table 3. Test results – H1, GDP at market prices.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.93	0.02	44.54	0.000	0.88	0.97
Covid-19 restrict.	-0.60	-0.07	-9.05	0.000	-0.74	-0.47

Table 4. Test results – H1, import.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.62	0.03	20.81	0.000	0.56	0.68
Covid-19 restrict.	-0.29	0.09	-3.03	0.004	-0.48	-0.10

Table 5. Test results – H1, export.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.65	0.03	23.15	0.000	0.59	0.71
Covid-19 restrict.	-0.12	0.09	-1.38	0.172	-0.30	-0.06

Table 6. Test results – H1, household expenditure consumption.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.91	0.02	49.19	0.000	0.87	0.94
Covid-19 restrict.	-0.72	0.06	-12.15	0.000	-0.84	-0.60

We then proceed to testing hypothesis 2 (step 2 in the causal steps approach, Table 1). Results are reported in Tables 7-11. The correlation between Covid-19 restrictions and the different lines of business of the port of Genoa is found to be negative and significant, as hypothesized. On the contrary, the correlation between Covid-19 restrictions and the container metric for Gioia Tauro is found to be significant, but positive. This last result does not support hypothesis 2. Overall, hypothesis 2 is supported with three out of our four metrics of port activity. The container metric for Gioia Tauro cannot be considered for the following steps of the causal steps approach (steps 3 and 4 in Table 1).

Table 7. Test results – H2, passengers, Genoa.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.51	0.03	16.13	0.000	0.45	0.57
Covid-19 restrict.	-0.62	0.10	-6.17	0.000	-0.83	-0.42

Table 8. Test results – H2, liquid bulks, Genoa.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.70	0.02	31.26	0.000	0.65	0.74
Covid-19 restrict.	-0.56	0.07	-7.87	0.000	-0.71	-0.42

Table 9. Test results – H2, containers, Genoa.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.55	0.03	18.35	0.000	0.49	0.61
Covid-19 restrict.	-0.28	0.10	-2.91	0.005	-0.47	-0.09

Table 10. Test results – H2, containers, Gioia Tauro.

	Coeff.	Std err	t	p> t	[0.025	0.975]
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const.	0.44	0.02	18.93	0.000	0.39	0.49
Covid-19 restrict.	0.19	0.07	2.52	0.015	0.04	0.34

Table 11. Test results – H2, composite port activity.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.67	0.02	31.47	0.000	0.63	0.72
Covid-19 restrict.	-0.46	0.07	-6.74	0.000	-0.60	-0.33

Tables 12-14 report testing results for hypothesis 3 (limited to composite port activity for the sake of brevity). Mediation is never found to be full. However, we have observed in Section 3 how a direct effect between Covid-19 restrictions and economic performance cannot be excluded even if port activity is included in the model, as port activity can be an important mediator, but does not reflect all production activities. No mediation is found between Covid-19 restrictions and household expenditure consumption with liquid bulks. No mediation is found between Covid-19 restrictions and GDP with passengers. Partial mediation is instead found for passengers with household expenditure consumption and import. Partial mediation is also supported with containers (Genoa) and with composite port activity for GDP, import and household expenditure consumption. In short, partial mediation is supported by all combinations of port activity and economic performance metrics, with only two exceptions (passengers/GDP and household expenditure consumption/liquid bulks). Finally, we have performed a Monte Carlo analysis and found that the strongest mediation effect is shown with composite port activity and GDP at market prices.

Table 12. Test results – H3, GDP at market prices and composite port activity.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.62	0.08	7.86	0.000	0.46	0.78
Covid-19 restrict.	-0.39	0.08	-4.95	0.000	-0.55	-0.23
Comp. port act.	0.46	0.11	4.01	0.000	0.23	0.68

Table 13. Test results – H3, import and composite port activity.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.7484	0.056	13.446	0.000	0.637	0.860
Covid-19 restrict.	-0.5214	0.066	-7.889	0.000	-0.654	-0.389
Comp. port act.	0.2837	0.084	3.384	0.001	0.116	0.452

Table 14. Test results – H3, household expenditure consumption and composite port activity.

	Coeff.	Std err	t	p> t	[0.025	0.975]
const.	0.66	0.07	9.19	0.000	0.51	0.80
Covid-19 restrict.	-0.55	0.07	-7.60	0.000	-0.69	-0.40

Comp. port act.	0.38	0.10	3.66	0.001	0.17	0.58
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5 Conclusions

Overall, results support a partial mediation effect of port activity, particularly when measured with the aggregate composite port activity metric. This suggests that future research could extend the model by measuring activity for a higher number of ports. This study has taken a first step towards understanding the overall economic impact of Covid-19 and the complex phenomena created by people’s changing habits. As these changes are often predicted to represent a “new normal,” a focus on actual production activities seems a promising direction to build a more comprehensive model of economic performance.

An important aspect of our study is the use of space data to measure port activity. These data are more timely and more widely available compared to the information on ports that can be gathered from official information available from traditional sources (e.g. the web sites of ports). This indicates an interesting potential role of space data as a source of timely information to observe and to anticipate economic trends.

From a managerial perspective, space data and, particularly, the AIS data used in this study represent a source of (quasi) real-time information that can be helpful to predict future economic trends. The use of space data enables a (quasi) real time and continuous monitoring of port activity. Ports are generally considered beacons of economic trends, as they lay upstream in the value chain of a variety of industries and play a key role in the procurement of raw materials. As a general observation, a real-time or quasi real-time indication of market trends has gained attention in a variety of contexts and could have broad application. The Covid-19 pandemic has made any analysis of historical sales data of little value for most companies and, particularly, for those who sell transportation services, including ferries. The analysis of historical sales data has broad application in an enterprise context to predict future sales and support numerous management activities, such as price optimization or budgeting. Given that predictions based on past sales have become inaccurate and non-dependable, due to the pandemic, many companies have started to consider more general predictions of economic trends as a source of useful information to complement their sales trends. Indicators of economic trends grounded on a real-time observation of tangible production activities could be of practical interest.

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