



Impact of COVID-19 epidemic on port operations: Evidence from Asian ports

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ABSTRACT

The outbreak of COVID-19 has impacted the shipping industry while the extent of the impact is still not fully understood. To quantitatively investigate the relationship between pandemic-related factors and port operations, a panel regression analysis is conducted using data from three important Asian ports, Shenzhen, Hong Kong, and Singapore. Daily data from the Automatic Identification System (AIS), Oxford COVID-19 Government Response Tracker (OxCGRT) database, and port authorities from January 2020 to December 2021 are utilized. Local newly confirmed cases of ports tend to negatively impact cargo throughput, while worldwide newly confirmed cases outside of ports tend to positively impact cargo throughput. Overall, the policy implications are that ports with better control of COVID-19 reap the benefits of more cargo throughput. In addition, countermeasures against COVID-19 and other epidemics should be designed deliberately to minimize the side-effect on port operations and maritime transportation.

1. Introduction

The COVID-19 crisis has been regarded as an ongoing concern for its comprehensive impact on every country (Menhat et al., 2021; Narasimha et al., 2021). With the goal of “flattening the curve” of infections, many countries have implemented strict prevention measures in order to curb the transmission of the disease. These measures include social distancing, quarantine controls, workplace closures, and lockdown restrictions, all of which significantly affect global mobility and transportation patterns (Coppola and Fabiis, 2021; Depellegrin et al., 2020; Tirachini and Cats, 2020). At the beginning of the epidemic outbreak, several sources reported a dramatic decline in sea, land, and air transport (Millefori et al., 2021; Tirachini and Cats, 2020). When coming to the re-opening phase, it remains unknown whether the pandemic crisis and constantly-adjust prevention measures will have impacts on transportation systems (Gkiotsalitis and Cats, 2021), and a survey among public transport companies showed that they appear to be anxious about the uncertainty of demand level recovery in the long term (Coppola and Fabiis, 2020). As a result, there still remains significant uncertainty about the recovery of cargo transportation and travel demand.

Among all sectors of transportation, the maritime transport sector is

dramatically affected because more than 80% of goods in the world are transported by maritime supply chain (Choquet and Sam-Lefebvre, 2020; UNCTAD, 2019). So far, the degree and path of COVID-19 impacting ports have not been fully explored. Although the pandemic is not a new issue in maritime (Akyurek and Bolat, 2020), in practice, different countermeasures result in varying performance in port operations. Compared with the United States and European countries, Asia has better controlled the epidemic, and thus the economic loss due to COVID-19 is relatively limited. From the perspective of the prevention policies for COVID-19, Asia can be divided into mainland China, other areas of China (e.g., Hong Kong), and countries other than China geographically. Specifically, mainland China has a solid foundation in the epidemic prevention medical system, which helps to perform well in handling the pandemic. Taking Hong Kong as the representative of other areas of China, it is difficult for the port to lock down swiftly and entirely due to its position as an “International shipping center” (Fu et al., 2021). Due to the critical role of ports, it is essential to evaluate their operational performance for resilience-building in the context of the unprecedented situation.

In general, while COVID-19 must have more or less impacts on different regions and ports in Asia, the operation of ports is still subject

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to the influence of the macro environment. Hence, analyzing the impact of COVID-19 on ports from the macro and micro levels can help us better elucidate the shortcomings in maritime transportation when facing the epidemic. Our study selects Shenzhen, Hong Kong, and Singapore as the typical representative of mainland China, other areas of China, and countries other than China. Owing to historical, social, and economic characteristics, not all regions manage this crisis in the same way (Choquet and Sam-Lefebvre, 2020), and the prevention and recovery measures in these regions vary to some extent. As shown in Fig. 1, there are similarities and differences in year-on-year growth of the port cargo throughput of Shenzhen port, Hong Kong port, and Singapore port during the COVID-19. Generally, the port cargo throughput decreased by some extent at the beginning of the epidemic, which indicated that ports lack the ability to cope with epidemic shocks (Corbet et al., 2020). As a result of the varied pandemic phases experienced by different geographic areas, ports also displayed various conditions. However, it is difficult to capture the driving factors behind and how much these factors play. Therefore, a systematic evaluation method needs to be proposed.

While there are increasing studies focusing on how the shipping industry reacts to COVID-19, there has been little research that compares ports' operation performance with respect to specific types of vessels by quantifying the epidemic severity, economic circumstance and government measures concurrently. The epidemic has highlighted the necessity of maritime transport as a crucial sector for the ongoing delivery of critical supplies and global trade during times of crisis, recovery, and return to normalcy (UNCTAD, 2020). As a result, with the post-COVID-19 era coming, understanding the variations in how ports are affected by unpredictable events and evaluating how different strategies are implemented by ports in the recovery stage are vital for finding out the capacity and incapacity, as well as building resilience into the global port network.

Considering that the pandemic is a fast-changing and elusive event, micro level data depicting maritime mobility is valuable. Fortunately, the Automatic Identification System (AIS) provides us with a good opportunity to capture the movements of individual vessels at the micro level. Indeed, AIS has been gradually used to assess the spread of the

virus in the maritime industry (March et al., 2021; Verschuur et al., 2021b; Wang et al., 2020). To explore the economic and social impacts of COVID-19 on port operations, an empirical investigation is conducted by combining data from the AIS dataset, Oxford COVID-19 Government Response Tracker (OxCGRT) database and port authorities. Inspired by the existing literature, our analysis is designed to provide answers to the following questions: (1) How much do the factors related to the COVID-19 epidemic itself, regional economy, and government measures contribute to the change of port operations? (2) Does it vary according to different ship types? (3) What are the implications for future port restoration?

To complement existing COVID-19 research on port operations, this paper builds a panel regression model to describe the situation. Panel data from Shenzhen, Hong Kong, and Singapore from January 2020 to December 2021 about port operation performance, epidemic, and containment measure indicators are selected to study. The remainder of this paper is organized as follows: Section 2 reviews the relevant literature on the research topics from the view of COVID-19, its impact on maritime transportation, and relevant analysis based on AIS big data. Section 3 introduces the methodology and data. Section 4 presents and discusses the research results. Lastly, Section 5 concludes and suggests directions for future research.

2. Literature review

Starting in December 2019, the outbreak of COVID-19 (SARS-COV-2) has swept the world quickly and infected hundreds of thousands of people. According to the World Health Organization (WHO), as of 31 December 2021, the COVID-19 pandemic has resulted in 285,581,643 confirmed cases globally, including 5,428,033 deaths (WHO, 2021). The distribution of the number of infected people in the world is visualized in Fig. 2. Affected by COVID-19, the world economy has experienced turmoil, regardless of the primary, secondary or tertiary sectors (Nicola et al., 2020). In view of the high connectivity of the whole world, as early as 30 January 2020, the WHO declared the COVID-19 outbreak as a Public Health Emergency of International Concern in order to attract the attention of countries (Sohrabi et al., 2020).

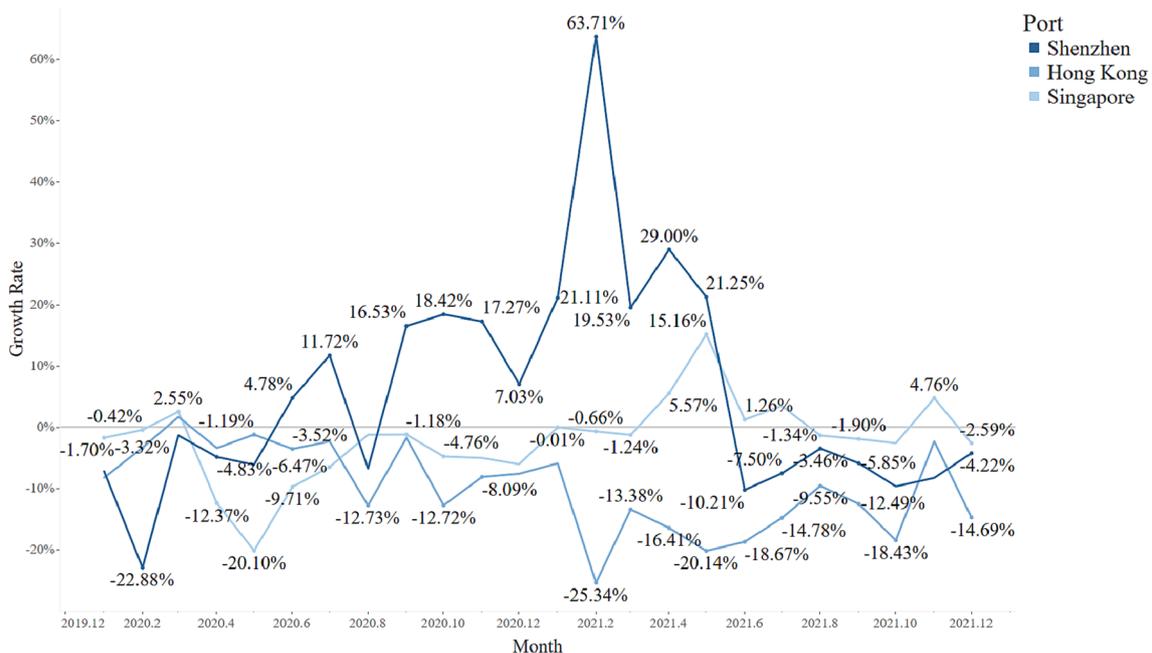


Fig. 1. The year-on-year growth rate of port cargo throughput in Shenzhen Port, Hong Kong Port, and Singapore Port from January 2020 to December 2021. (Source: Authors' elaboration on data from the Ministry of Transport of China(Available at: <https://www.mot.gov.cn/tongjishuju/gangkouhuowulvketi/>), Singapore Department of Statics(Available at: <https://www.singstat.gov.sg/find-data/search-by-theme/industry/transport/latest-data>), Marine Department of the Hong Kong (Available at: <https://www.mardep.gov.hk/sc/fact/portstat.html#4>).

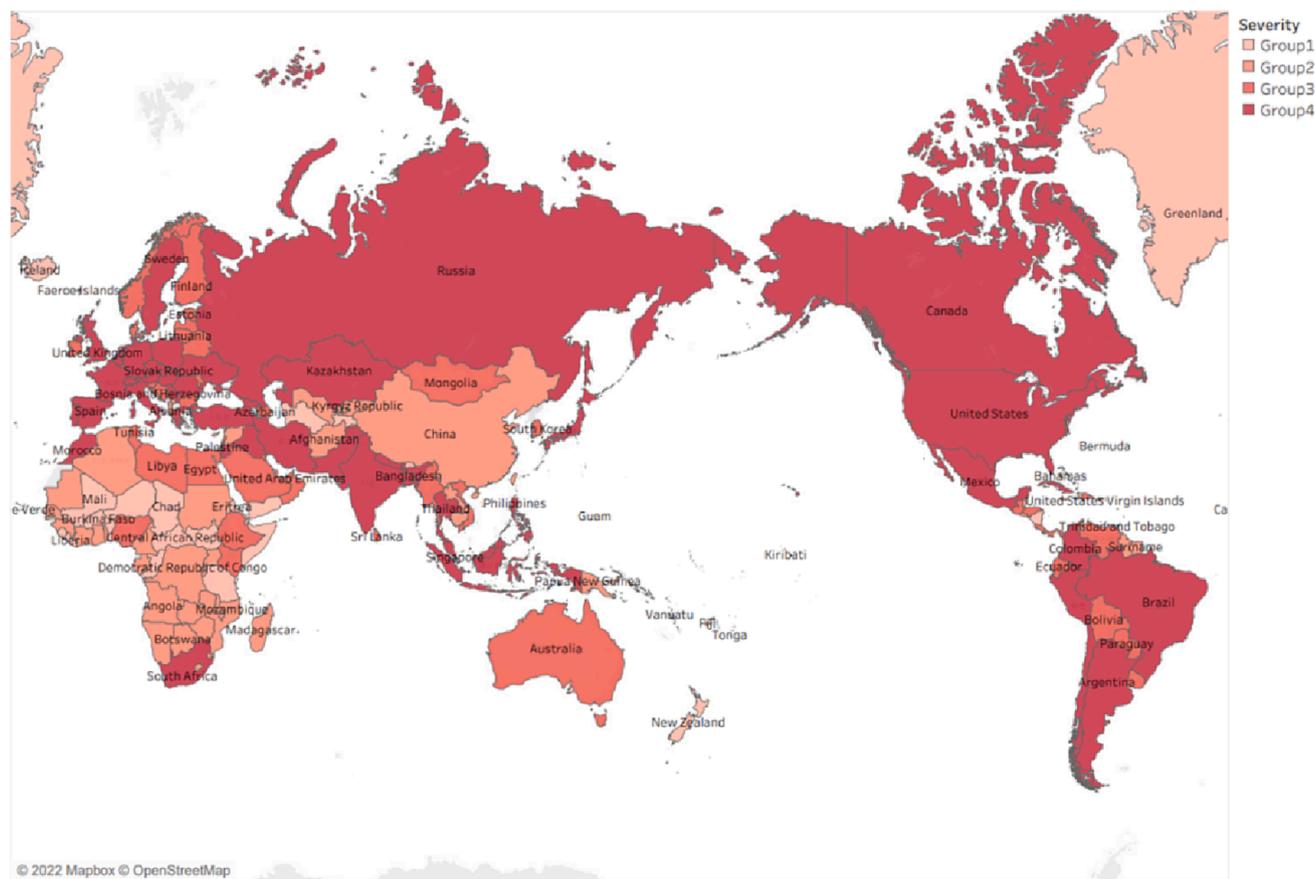


Fig. 2. An overview of cumulative confirmed cases in each country as of 31 December 2021. (Source: Authors' elaboration on OxCGRT data).

Specifically, the severity of the epidemic has been divided into four levels. Group (1) refers to countries with $<21,735$ (the lowest quantile in all) confirmed cases. Group 2 refers to countries with confirmed cases between the quantile and median ($21,735 \sim 229,921$). And so on.²

At the early stage of the COVID-19 epidemic, most studies in maritime transportation focused on the cruise industry by investigating specific cases for the reason that cruise ship acts as an epicenter of COVID-19 cases in the marine industry with its characteristics of large size and confined space. It is reported that ports that continued to accept cruise ships reported more confirmed cases than those that did not. Mizumoto et al. (2020) employ a statistical model to estimate the asymptomatic proportion on board the Diamond Princess cruise ship, the first known case in the maritime field. They find that the infection rate on the Diamond Princess cruise ship was 17%, much higher than any other infection. Soon afterward, studies extended to more aspects of maritime domain as the spread of the epidemic had led the maritime industry into chaos. Cengiz and Turan (2021) conduct an online survey among various maritime industry practitioners from 21 countries, investigating the business effects of the epidemic on the global maritime industry. Abous et al. (2021) apply the Autoregressive Distributed Lag (ARDL) cointegration technique to evaluate the short-term and long-term relationship between the number of TEUs, the cumulative number of COVID-19 cases and death in the Tanger Med container port in Morocco. Yazir et al. (2020) discuss maritime industry's development trends and challenges in dry bulk, tanker, container, and cruise sectors, respectively, based on the literature.

With the COVID-19 epidemic continuing to develop, Notteboom et al. (2021) compare the difference between the financial crisis and

COVID-19 in terms of the strategic behavior of shipping lines, vessel calls, container port connectivity, and so on. They conclude that port resilience to disruption remained a major challenge for the port industries. Gui et al. (2022) hold the view that the impacts of COVID-19 on the economy, society, and the port sector greatly outweigh that of "SARS" in 2003. Considering that the advent of the COVID-19 has both immediate and future effects on maritime transportation sector, Koyuncu et al. (2021) apply Seasonal Autoregressive Integrated Moving Average (SARIMA) and Exponential Smoothing State Space (ETS) models to forecast the RWI/ISL Container Throughput Index and verify the validity of the models. Their results show that the decrease in the index will continue in the coming three months. Zhao et al. (2022) adopt the exponential smoothing model to anticipate the BDI, CCBFI, and container throughputs with and without the impact of COVID-19. Tai et al. (2021) simulate the impacts of COVID-19 on Shanghai port by establishing a System Dynamics model and observe the differences in port throughput with different scenarios that the epidemic is unchanged, aggravated, and weakened.

As the impact of COVID-19 on the whole maritime industry became increasingly prominent over time, scholars gradually found that not only the COVID-19 itself could affect maritime transportation, but the economic situation and government countermeasure in this particular period also play important roles in port operation, which have usually been overlooked or separated in previous studies. Xu et al. (2021b) construct a panel regression model with time dummies, taking epidemic indicators and city-level economic data into consideration. They use data from 14 major ports in China and report that different variables have different effects on import and export cargo throughputs. In addition, port operations also vary with time. Furthermore, from the perspective of shipping trade in China with three different regions, Xu et al. (2021a) further analyze the relationships between shipping trade volume and various variables. They find that COVID-19 has both

² Available at: <https://github.com/OxCGRT/covid-policy-tracker/tree/master/data>.

negative and positive impacts on the shipping trade in China with other regions. Similarly, Michail and Melas (2020) use a GRACH regression to examine the impact of the epidemic on freight rates. Besides that, as a complement to the simple OLS framework, they use the impulse response function of the Vector Autoregression (VAR) model to examine how the whole system responds to unexpected shock. The experimental results of Michail and Melas (2020) indicate that there are second-round and third-round effects brought by the epidemic, among which dry bulk and clean tankers vessels are highly affected.

With the continuous development of technology, Automatic Identification System (AIS) data has become a useful tool to trace the mobility and movements of sea activity. According to the 2002 Safety of Life at Sea (SOLAS) convention, all vessels above 300 GT (gross tonnage) must be fitted with an AIS transponder. As a result, the AIS data can reflect the movements at sea to the greatest extent. Research using AIS data has witnessed a dramatic increase in recent years, focusing mainly on collision avoidance, ship behavior analysis, and route planning (Liu et al., 2020). In order to capture the real-time change in marine traffic, many researchers also used AIS data to evaluate the impact of COVID-19 on maritime transportation. Depellegrin et al. (2020) analyze the effects of national lockdown policies in the EU maritime region using AIS data of different types of vessels. Their results show that passenger and fishing vessels register high trajectory variations in vessel trajectory analysis. Moreover, Leonardo M. Millefori et al. (2021) compare the mobility of all categories of commercial shipping based on the computation of Cumulative Navigated Miles (CNM) of all ships, number of active and idle ships, and feet average speed via AIS. It is found that shipping mobility has been affected negatively, among which the most affected traffic segment is passenger ships, followed by container ships. Considering that maritime trade is closely related to the global economy, Verschuur et al. (2021a) derive a new high-frequency indicator by using AIS data as a proxy of economic activity. The results prove that the losses of global maritime trade were 7.0% to 9.6% during the first eight months of 2020, and ports with specific supply chains (e.g., oil and vehicle manufacturing) experienced larger losses in the context of the epidemic. Taking Shanghai port, Ningbo-Zhoushan port, and Tianjin port as examples, Zhu et al. (2020) compare the number of arriving ships and the berth time of ships of container vessels between 2019 and 2020. Numerical results suggest that the COVID-19 pandemic significantly reduces the average berth time of ships, while the number of ships arriving at China's ports is not affected. From an environmentally-friendly perspective, Shi and Weng (2021) compare the AIS data of merchant ships in February 2019 and February 2020 in Shanghai port waters, including ship count and unit ship emission intensity. Their results call for the use of shore power equipment for merchant ships during the epidemic. Considering that COVID-19 will last for a long time in the coming years, studies on controlling the disease and recovering the port economy have also become a major concern. Wang et al. (2020) propose a novel COVID-19 ship risk assessment method by processing AIS and country-level data to calculate ship exposure indexes. They prove that the proposed approach successfully provides a daily trace of the risk level of an experimental ship, which could provide relevant countries

with decision support mechanisms.

By summarizing the existing literature with regard to the impact of COVID-19 on the shipping industry, the majority of the research targets the impact on a specific country, paying little attention to the generality between different economies. Moreover, the port local and worldwide development of COVID-19 should be taken into consideration during the pandemic, which is highly related to the changes in port operations. As Verschuur et al. (2020) point out, there is little empirical evidence in real-world situations related to port disruptions caused by natural disasters. Thus, it offers a great opportunity for us to have a deeper insight into port operation from both macro and micro levels. Taking Shenzhen, Hong Kong, and Singapore as our research objects, this research explores the complex relationship between port operations and the factors related to the epidemic. Our research aims to shed some light on the gaps in the existing literature and helps interested parties make recovery decisions, including shipping companies, owners, managers, inspectors, and policymakers.

3. Methodology and data

3.1. Methodology

This study aims to explore the primary determinants of port operations during the epidemic. In our empirical analysis, port operations are proxied by port cargo throughput, as well as the arriving and departing calls of various specific types of vessels. Being the most direct factor, the newly confirmed cases are used to indicate the severity of COVID-19. Besides the severity of COVID-19, port operation is still subject to macroeconomic activity that is represented by Purchasing Managers' Index (PMI) of the local economies (Xu et al., 2021b). Also, in coping with COVID-19, governments have come out with different measures that might effectively restrict people's movement and, consequently, the operations of ports (Xu et al., 2021a). Considering the cross-section and time effects for the port performance, the panel data regression model is adopted in this study. A detailed description of the variables is presented in Table 1.

A panel regression approach has been adopted to investigate how the explanatory variables affect port operation performance in the context of COVID-19. Regarding the model specification, panel data analysis needs to consider fixed or random effect settings. As random effect requires the size of cross-section to be large, the fixed-effect setting has been chosen. In addition, port operations in terms of overall throughput, vessel arrival and vessel departure are not uniform with time. Ports are relatively busy in certain months. Therefore, the time-dependent phenomenon has been taken into consideration by controlling for the time effect. Overall, the regression model adopted is as follows:

$$Y_{i,t} = \alpha_i + \gamma_t + \sum_{j=0}^J \beta_1 \ln Nccl_{i,t-j} + \sum_{k=0}^K \beta_2 \ln Nccw_{i,t-k} + \sum_{m=0}^1 \beta_3 PMI_{i,t-m} + \sum_{n=0}^1 \beta_4 Str_{i,t-n} + \mu_{i,t}, \tag{1}$$

Table 1
Definition of the variables.

Variable	Symbol	Definition
Port cargo throughput	Ct	Cargo throughput
Arriving container vessel port call	Arr_Cpc	Number of container vessel calls arriving at ports
Arriving dry bulk vessel port call	Arr_Dbpc	Number of dry bulk vessel calls arriving at ports
Arriving liquid bulk vessel port call	Arr_Lbpc	Number of liquid bulk vessel calls arriving at ports
Departing container vessel port call	Dep_Cpc	Number of container vessel calls leaving ports
Departing dry bulk vessel port call	Dep_Dbpc	Number of dry bulk vessel calls leaving ports
Departing liquid bulk vessel port call	Dep_Lbpc	Number of liquid bulk vessel calls leaving ports
Newly confirmed cases (Local)	Nccl	Newly confirmed case of the port city
Newly confirmed cases (Worldwide)	Nccw	Newly confirmed case outside the port city
Government Stringency Index	Str	Government stringency index
Purchasing Managers' Index	PMI	Purchasing Managers' Index

Table 2
Descriptive statistics.

Variable	Unit	Mean	Maximum	Minimum	Std. Dev.	Observations
Ct	10000tons	3051.153	5334.000	1072.000	1392.153	24
Arr_Cpc	Units	1020.472	1304.000	581.000	167.888	731
Arr_Dbpc	Units	137.292	295.000	26.000	73.796	731
Arr_Lbpc	Units	1194.083	3384.000	31.000	1368.658	731
Dep_Cpc	Units	1016.597	1315.000	607.000	170.484	731
Dep_Dbpc	Units	135.583	290.000	23.000	73.429	731
Dep_Lbpc	Units	1189.319	3389.000	32.000	1364.673	731
Nccl	Units	4104.319	101853.000	7.000	14730.090	731
Nccw	Units	11965975.000	24696919.000	9852.000	7334767.000	731
PMI	%	49.149	53.300	33.100	4.006	24
Str	%	54.019	78.272	18.698	12.911	731

where the subscript i denotes the port index and t is the time index. $Y_{i,t}$ is the dependent variable capturing port performance in terms of cargo throughput and port calls of different vessels. That is, $Y_{i,t}$ takes a natural-logarithm form of the element of a set S containing seven elements, $S = \{Ct_{i,t}, Arr_Cpc_{i,t}, Arr_Dbpc_{i,t}, Arr_Lbpc_{i,t}, Dep_Cpc_{i,t}, Dep_Dbpc_{i,t}, Dep_Lbpc_{i,t}\}'$. The newly confirmed cases of and outside the cities in which the ports locate might have different meanings for the ports. As a result, $Nccl_{i,t}$ are used to indicate the newly confirmed cases of the port city, and $Nccw_{i,t}$ are the newly confirmed cases outside the port city i at time t . $PMI_{i,t}$ is the macroeconomic variable, referring to Purchasing Managers' Index (PMI). The variable $Str_{i,t}$ is the government stringency index developed by Oxford COVID-19 Government Response Tracker (OxCGRT) database. α and β are the coefficients of independent variables. J and K are the lag orders in view of the lagged effects of the newly confirmed cases of COVID-19. Considering that there may be a lag period between the economy and the shipping industry (Xu et al., 2021b), the first-order lag of PMI and government stringency index have been used in the research models. $\mu_{i,t}$ is the error term. The first fixed effect coefficient α_i captures the individual effect that port operation doesn't show heterogeneity in time but varies according to the port itself. Besides that, port operation displays differences with time points. γ_t represents this time point fixed effect.

3.2. Data

The ports of Shenzhen, Hong Kong and Singapore with presentative and suitable data from January 2020 to December 2021 have been chosen. The data has been compiled from port authorities and relevant databases.

The port operation indicators include port cargo throughput and the daily number of vessel calls, provided by relevant port authorities and the AIS database. The AIS database is provided by the platform "Vessel Value Visualization" Developed by Cosco Shipping Technology Company Limited (Cosco, 2021), which includes static, dynamic, and voyage-related data. Specifically, the static data used by this study contains IMO, maritime mobile service identity (MMSI), ship type, ship

Table 3
Correlation coefficients of variables.

	Ct	Arr_Cpc	Arr_Dbpc	Arr_Lbpc	Dep_Cpc	Dep_Dbpc	Dep_Lbpc	Nccl	Nccw	PMI	Str
Ct	1										
Arr_Cpc	0.641***	1									
Arr_Dbpc	-0.786***	-0.516***	1								
Arr_Lbpc	0.755***	0.823***	-0.792***	1							
Dep_Cpc	0.613***	0.980***	-0.485***	0.802***	1						
Dep_Dbpc	-0.782***	-0.508***	0.996***	-0.785***	-0.466***	1					
Dep_Lbpc	0.753***	0.823***	-0.791***	1.000***	0.804***	-0.784***	1				
Nccl	0.502***	0.400***	-0.665***	0.588***	0.365***	-0.661***	0.587***	1			
Nccw	-0.082**	-0.041	0.020	0	-0.064	0.015	0.001	0.195	1		
PMI	0.208*	-0.055	0.003*	-0.028	-0.060	-0.009	-0.032	-0.138	0.469***	1	
Str	-0.372***	-0.146	0.190*	-0.142	-0.139	0.196*	-0.143	0.131	0.369***	-0.130	1

Note: ***denotes $p < 0.01$, **denotes $p < 0.05$, *denotes $p < 0.1$, respectively.

name and flag. Dynamic data includes position, speed and course over the ground. Other voyage-related information like destination and estimated time of arrival are also contained.

The number of newly confirmed cases is employed to measure the epidemic severity. Given that the local newly confirmed cases may reduce the workforce of the ports and disrupt the port operation, and in the same reasoning, newly confirmed cases worldwide outside the ports cause economic activities worldwide to a halt and might increase demand for overseas goods, the newly confirmed cases of and outside the cities in which the ports locate have been calculated to measure different epidemic severity. The corresponding data is obtained from the Oxford COVID-19 Government Response Tracker (OxCGRT) database, which is one of the most authoritative datasets for COVID-19-related research (Hale et al., 2021).

The government stringency index sourced from OxCGRT database is used to measure the government's response. In coping with COVID-19, governments have come out with different measures that might effectively restrict people's movement and, consequently, the operations of ports. Generally, the port prevention policies are tightened with the severity of the epidemic. Given the availability of data, the government stringency index of Guangdong Province is used to represent Shenzhen to ensure the accuracy of data to the greatest extent.

Besides the severity of COVID-19, port operation is still subject to macroeconomic activity that is represented by Purchasing Managers' Index (PMI) of the local economies. The PMI index of China, Hong Kong, and Singapore, abstracted from a third-party database Wind, has been used to represent the situation of the regional economy, as it is the earliest indicator to reflect the nation's economic strength (Joseph et al., 2011). Overall, the descriptive summary of the variables is reported in Table 2.

Before proceeding with the regression model, one thing should be addressed: data from different resources must be merged into a panel. Monthly data has been used as the minimal unit since both the port cargo throughput and PMI data are provided on a monthly basis. As a result, daily data of newly confirmed cases are converted into monthly data by accumulating each month, and the daily government stringency

Table 4
Results of unit root tests.

Variables	Ct	Arr_Cpc	Arr_Dbpc	Arr_Lbpc	Dep_Cpc	Dep_Dbpc
ADF	29.842***	20.988***	27.499***	18.512***	13.458**	24.243***
PP	30.075***	17.076***	17.881***	18.297***	13.155**	18.564***
	Dep_Lbpc	Nccl	Nccw	PMI	Str	
ADF	16.440***	15.074**	32.225***	22.659***	16.692***	
PP	16.280***	16.469***	790.172***	21.029***	24.323***	

Note: ***denotes $p < 0.01$, **denotes $p < 0.05$, *denotes $p < 0.1$, respectively.

index is averaged to obtain the monthly data. It is also found that there is no multicollinearity problem among the explanatory variables in the regression model, as shown in Table 3.

4. Results and discussion

4.1. Results

In this subsection, the panel data regression model is applied to analyze the whole port operation performance and then calls of specific types of ships, including container vessels, dry bulk vessels and liquid bulk vessels. Before model regressions, unit root tests are conducted to judge whether all the data series are stationary, where the most commonly used methods Augmented Dickey-Fuller (ADF) test and the Phillips and Perron (PP) test are conducted in this study (Dickey and Fuller, 1979; Phillips and Perron, 1988). The results of the ADF and PP tests of the time series used in the panel regression models are shown in Table 4. All the variables are highly significant at the 5% level. As the tests have a unit root hypothesis, all the time series are stationary.

In the regressions, the information criteria AIC is used to determine the lag orders J and K for the newly confirmed COVID-19 cases. Table 5 reports the estimation results when the dependent variables are cargo throughput and vessel calls according to Eq. (1). Regarding cargo throughput, the setting of $J = 1$ and $K = 0$ is favored by AIC. The findings show that the local newly confirmed cases negatively impact cargo throughput at the 10% significance level, which is consistent with the conclusion of Xu et al. (2021b) for the role of the severity of the epidemic in lowering both import and export cargo throughputs. While the newly confirmed cases worldwide outside the port have a significantly positive impact, with a 1% increase of newly confirmed cases

worldwide implying a 0.071% increment of cargo throughput. The coefficients of the remaining control variables are all negative and in our expected signs, which are supported by the statistically significant and negative coefficients for both variables, with coefficients for lagged PMI and government stringency -0.014 and -0.008 , respectively.

Moreover, the regression results of different vessels are reported in columns 3 to 8 of Table 5. The settings of lag orders J and K are also determined by the information criteria AIC. As for vessels arriving at Shenzhen, Hong Kong and Singapore ports, it is observed that local newly confirmed cases have a negative impact on dry bulk vessels and liquid bulk vessels with significance at 5% level. A 1% increase in local epidemic severity is shown to decrease arriving dry bulk vessels and liquid bulk vessels by 0.078% and 0.025%, respectively. Similar to the regression of cargo throughput, an increase in worldwide newly confirmed cases outside of ports imposes a positive effect on calls of arriving vessels in the concurrent month though the effect is insignificant. A positive effect of the PMI index for arriving dry bulk vessels is observed, with a regression coefficient of 0.003. The effects of government stringency index vary with respect to the types of vessels and lag periods. The three types of vessels are subject to the negative impact of the government containment measures of either the current month or lagged month. In addition, container vessels are the only vessel type receiving a positive effect from the lagged stringency.

Compared with arriving vessels, the departing vessels are more vulnerable to newly confirmed cases of COVID-19. With the increase in newly confirmed local cases, all vessels departing from the ports are negatively impacted. For newly confirmed worldwide cases outside the ports, the effects vary for different vessels. The effect is negative on container vessels while positive on liquid bulk vessels, with the regression coefficient of -0.02 and 0.054 , respectively. As with the arriving

Table 5
Regression results of port cargo throughput and vessel calls.

Variable	Ct	Arrival			Department		
		Arr_Cpc	Arr_Dbpc	Arr_Lbpc	Dep_Cpc	Dep_Dbpc	Dep_Lbpc
Nccl	0.008 (0.016)	0.012 (0.012)	-0.078*** (0.023)	-0.025** (0.011)	0.013 (0.01)	-0.081*** (0.025)	-0.002 (0.019)
Nccl[-1]	-0.027* (0.016)	-0.015 (0.012)			-0.019* (0.01)		-0.038** (0.019)
Nccw	0.071*** (0.017)	0.248 (0.156)	0.269 (0.298)	-0.047 (0.249)	-0.02* (0.011)	0.207 (0.549)	0.054** (0.021)
Nccw[-1]		-0.195 (0.121)	-1.447 (1.361)	0.02 (0.68)		-2.047 (1.501)	
Nccw[-2]			0.824 (0.795)	0.007 (0.397)		1.269 (0.877)	
PMI	-0.001 (0.006)	-0.001 (0.005)	0.002 (0.016)	-0.006 (0.008)	0.001 (0.004)	0.019 (0.018)	-0.013* (0.007)
PMI[-1]	-0.014** (0.005)	-0.003 (0.004)	0.003** (0.012)	0.006 (0.006)	-0.004 (0.003)	0.031** (0.013)	0.002 (0.006)
Str	-0.008*** (0.002)	-0.005*** (0.002)	0.008 (0.005)	-0.007** (0.003)	-0.004*** (0.001)	0.011* (0.006)	-0.01*** (0.003)
Str[-1]	0.002 (0.003)	0.005** (0.002)	-0.015*** (0.005)	0.002 (0.003)	0.004** (0.002)	-0.017*** (0.006)	0.006* (0.003)
Constant	7.923***	6.145***	8.76***	6.893***	7.306***	12.269***	6.156***
Observations	69	69	69	69	69	69	69
R-squared	0.781	0.761	0.726	0.613	0.838	0.705	0.707

Note: Figures in parentheses indicate standard errors, where *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, respectively. Lagged values are in brackets[-]. Lag orders of newly confirmed cases are determined by the information criterion AIC.

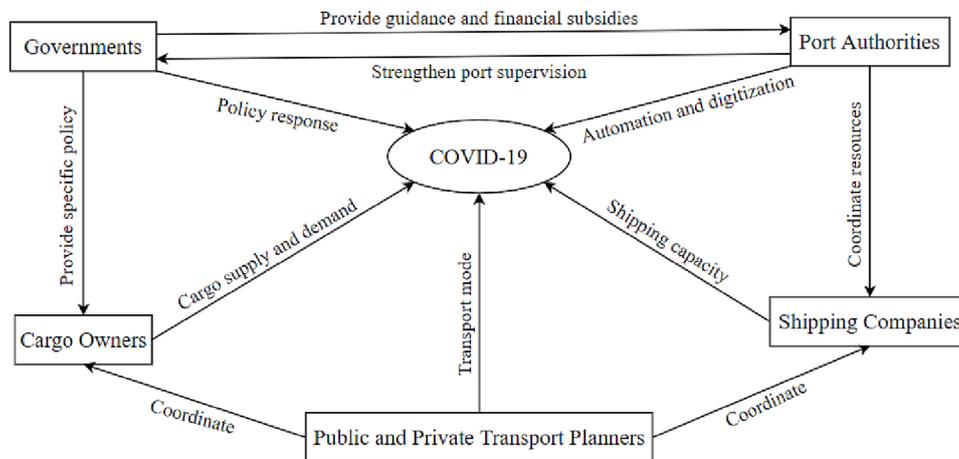


Fig. 3. Stakeholder mapping in maritime transportation during COVID-19.

dry bulk vessels, the one-month lagged PMI index imposes a positive effect on the departure of dry bulk vessels. A 1% increase in PMI index yields a 0.031% rise in the number of departing dry bulk vessels. On the contrary, a negative impact of PMI index is observed on the current month's departing liquid bulk vessels, with a regression coefficient of -0.013 . Regarding the effects of government stringency policies on the number of vessels departing from ports, with the tightening of epidemic prevention and control policies, both container and liquid bulk vessels decrease in the first month and then increase in the second month. At the same time, the impacts on dry bulk vessels show an opposite pattern.

4.2. Discussion

The findings based on port cargo throughput and vessel calls suggest that the outbreak of the epidemic has impacted ports' throughput efficiency, as well as the number of vessel calls. However, the epidemic outside the port tends to have the opposite effect. This may be because compared with other areas around the world, Asia has maintained a relatively low virus infection rate, maintaining its export capacity while the production of those high infection countries has been halted. Breaking the port operation down into arriving-departing vessels as well as vessel types, the arriving vessels are impacted by the local newly confirmed cases while departing vessels are influenced by both local and worldwide newly confirmed cases. The different behaviors of the arriving and departing vessels imply the surging demand of the West for oversea goods. Affected by the epidemic, the consumption patterns of European and American countries have shifted a lot, and the volume of goods imported from China has been extensively promoted, given China's well control for the epidemic during the sample period. As a result, adjusting shipping capacity and strengthening port supervision to the changes in demand and supply of goods proactively can help to mitigate the negative impact of the epidemic's severity on port operations. Moreover, port authorities should accelerate the process of automation and digitization to reduce personnel contacts and operational interruptions caused by the epidemic.

Regarding the effects of controlled variables, the one-month lagged PMI index imposes a significantly positive effect only on the activity of dry bulk vessels. Emergency events could extend the economic recovery period, which has hindered the positive impact of economic recovery on cargo throughput and vessel calls. One possible explanation could be that dry bulk vessels are responsible for the transportation of bulk commodities and strategic goods during the pandemic, among which the departing vessels are more affected. For dry bulk vessels, shipping companies should increase capacity to meet the needs of epidemic prevention materials, while port authorities should coordinate the resources within the port to improve cargo handling efficiency. For container and liquid bulk vessels, the government can consider

providing financial subsidies to stimulate the growth of the number of vessels.

Moreover, the government stringency index tends to have a positive impact on port operations with a lagged effect, which is somehow in line with the finding of Xu et al. (2021b). It is also observed that the lagged effects of government preventive measures on the numbers of container and liquid bulk vessels are positive. This might be because implementing strict prevention measures delays the handling of vessels, causing vessels to accumulate and be handled in the next month. However, government preventions actually had a concurrently negative impact on port operation. This result supports the study that the lockdown measure decreased vessel activity during the pandemic (Depellegrin et al., 2020). Strict inspection and quarantine measures at ports during the epidemic will extend the berthing and anchoring time of ships, resulting in less efficient port operations. Overall, government preventive measures tend to disrupt the port operations by slowing down the handle of vessels, causing vessels to accumulate. Once the situation of epidemic of the ports improves, vessel handling recovers so that the number of vessel calls increases in the subsequent month.

The results of the empirical analysis establish that the development of COVID-19, economic situation, and government measures have the explanatory capability to account for the changes in Asian port cargo throughput and vessel calls during COVID-19. The findings of this study build on prior research which proved that the pandemic had an impact on maritime fields (Notteboom et al., 2021; Verschuur et al., 2021a; Xu et al., 2021a; Xu et al., 2021b). Different from previous studies, our study investigates the impacts of the pandemic in the dimensions of arriving-departing vessels and vessel types. As illustrated in the stakeholder mapping in Fig. 3, the findings of this study should be of great assistance to stakeholders like governments, port authorities, cargo owners, shipping companies, as well as public and private transport planners when dealing with emergencies like COVID-19. Governments should consider the potential impact on ports beforehand so as to implement more appropriate measures when devising strategies. In order to achieve a faster rebound in growth during the post-epidemic era, the government can provide more specific policy support such as tax cut and appropriate marketing measures for container and liquid bulk cargo. Port authorities should also take note of the varied impact of preventive measures on different types of vessels and coordinate corresponding berths in advance. Moreover, regular communication among public and private transport planners, shipping companies and cargo owners with alternative transportation methods beyond maritime options are crucial for timely delivery of goods.

5. Conclusion

The outbreak of COVID-19 has led to varying levels of loss on

maritime transportation as the situation is different among regions. In this study, Asian ports represented by Shenzhen, Hong Kong, and Singapore have been chosen to investigate the impact of COVID-19 on port operations. The main conclusions are as follows. First, the local newly confirmed cases have significantly negative effects on port operations, among which dry bulk vessels have been more severely affected by the epidemic. In contrast, the worldwide newly confirmed cases outside the port tend to promote the recovery of ports, indicating that the impacts of the pandemic may have two sides on ports. Second, the economy's ability to stimulate the recovery of port operations is found to be almost ineffective during the epidemic. Third, there is a negative correlation between containment measures and port operations. As a result, it is challenging to promote the recovery of port operations under certain prevention measures in the short term.

The study explores the relationship between the pandemic, economic situation, government measures and port operations in three Asian ports. As the pandemic will have impacts on port stakeholders such as governments, port authorities, shipping companies, cargo owners, public and private transport planners, our findings could provide some managerial implications for various stakeholders. First, in designing containment measures, governments and port authorities should be cautious of the potential negative effects of the measures and minimize the congestion and delay of vessels caused. Moreover, it is essential for governments to devise distinct policies for varying types of vessels, and establish collaborative partnerships with cargo owners and port authorities to provide financial subsidies. Second, it presents a favorable opportunity for ports to transform their existing office mode and speed up the digitalizing process. Third, timely adaptation of shipping capacity and route arrangement are crucial in accordance with changes in supply and demand of goods.

Moreover, there are some practical implications. First, ports with a smaller number of local cases would reap the benefits of better handling capacity and cargo throughput. As a result, port workers should take the highest level of precautions, such as receiving regular vaccinations, storing epidemic prevention materials, familiarizing themselves with epidemic prevention guidelines, and so on. Second, an effective approach to enhancing port supply chain efficiency is to strengthen cooperation between port stakeholders. The adverse impact of COVID-19 on port operations can be mitigated through close collaboration among different departments.

This study has some limitations and needs further research. The scope of the analysis is restricted by the limited availability of data, and the long-term consequence of the outbreak in each port is still unknown and worth studying. Also, the proposed approaches in this research can only provide a general overview of the impacts, which is incapable of more detailed stages. As a result, future research can be expanded in several ways. First, as time progresses, the structure of shipping network in the world is bound to change during and after the epidemic. Future research can explore how the global maritime transportation network will be going on after COVID-19. Second, considering that the occurrence of unconventional emergencies like COVID-19 is hard to predict, apart from post-event analysis, building a flexible network in the pre-event period is also very important. Future research will focus on the problem of resilience enhancement, aiming at capacity sharing and risk dispersing among regional shipping networks.

CRediT authorship contribution statement

Yimiao Gu: Conceptualization, Methodology, Software. **Yingsi Chen:** Data curation, Writing – original draft. **Xinbo Wang:** Visualization, Investigation. **Zhenxi Chen:** Software, Validation, 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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