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The container transport system during Covid-19: An analysis through the prism of complex networks

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Research issue

- How a global shock such as the Covid-19 crisis affected the maritime transport system?

1) Impact on the hierarchy of ports at the continental level
2) Impact on ports depending on their network characteristics

This paper is a first step to understand this issue, through the prism of network analysis

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Research background

- Vulnerability analysis of maritime networks and hubs
  - Short/long term effects of shocks (Xu & Itoh, 2018, Rousset & Ducruet, 2020)

- Specific works on the Covid19 crisis
  - Comparison with the 2008/09 crisis (Notteboom et al., 2021)
  - Consequences on international trade (Verschuur et al, 2020)

Pending issues: How the network of ports was affected?
Did the Covid-19 mitigation measures affected regional port hierarchies?

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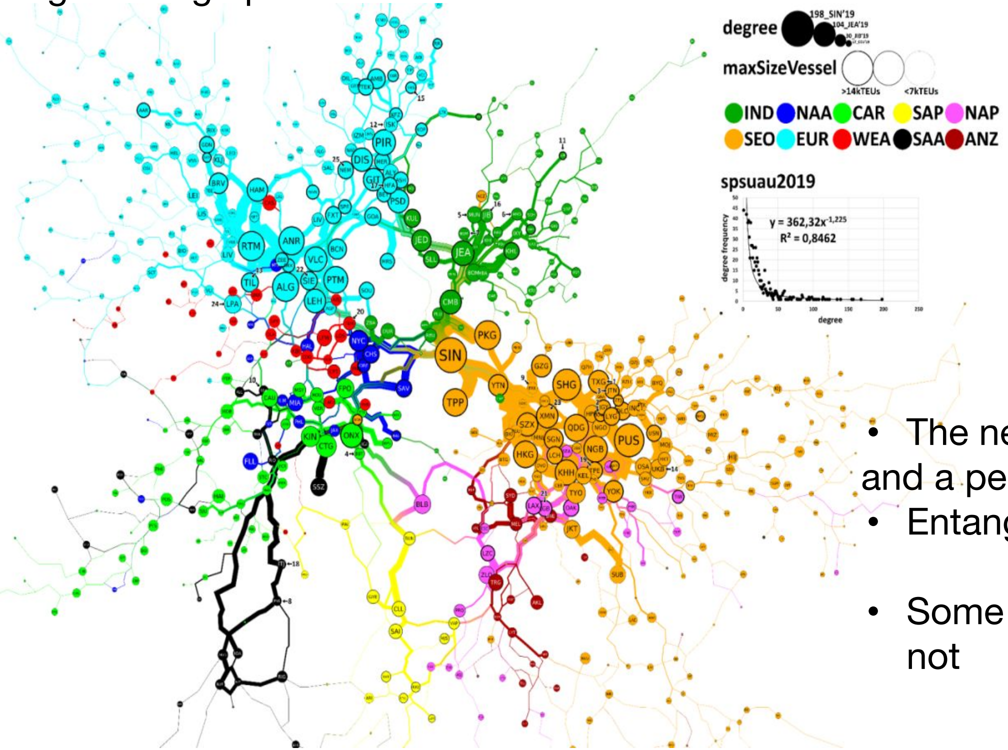
Data

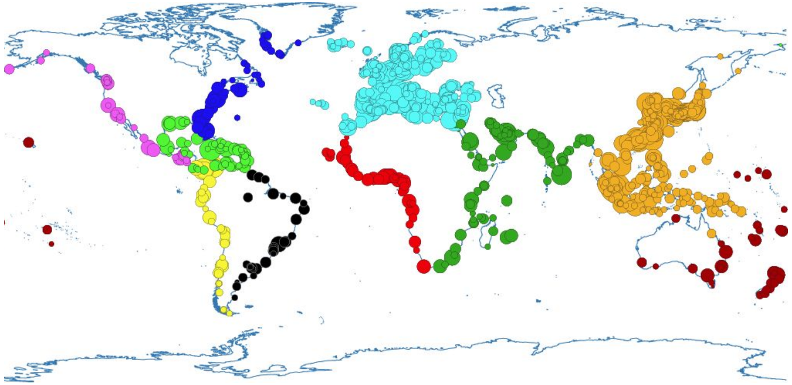
- Automatic Identification System (AIS) data on vessel movements between ports. Source: Vesselfinder
- Period of analysis: Spring-Summer-Autumn 2019 & 2020

			2019	2020
			572.713	**549.968**
Vessels		Number	5.744	5.673
	avg size (TEUs)	Average	3.552	3.592
Ports		Number	**1.001**	**1.010**
	avg size (TEUs)		**2.114**	**2.056**

Visualization of the port network

Left: Yi-Fan Hu network visualization
Right: Geographical location





- The network has a core (Europe/Asia)
and a periphery (South)
- Entanglement between Africa, America, Europe
  - Between both sides of Pacific
- Some proximities are geographical while others not

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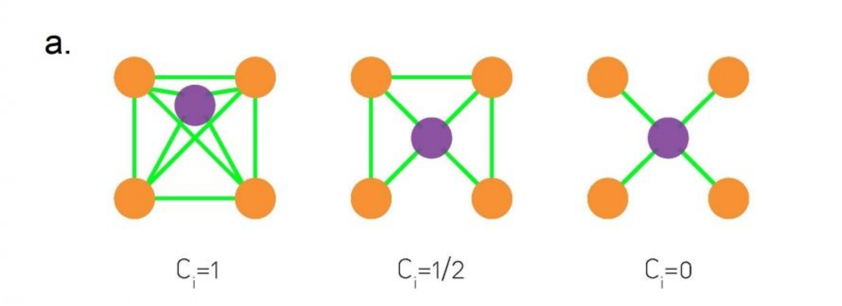
Methodology (1)

- Hypothesis: The networks of the different maritime companies are considered as a single network

- Classical network analysis indicators (ports):
  - **Port degree** (number of direct connections between ports)
  - **Weighted degree** (number of direct connections weighted by vessel capacity)
  - **Betweenness centrality** (number of shortest paths connecting two random nodes and passing through a given node)
  - **Clustering coefficient** (measure of neighbourhood interconnection)

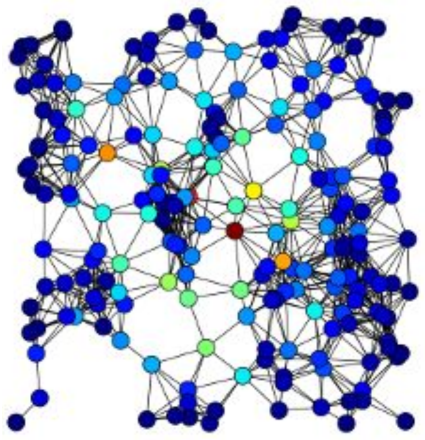
Methodology (2)

The local **clustering coefficient** captures the degree to which the neighbors of a given port are linked between them.



Barabási, 2016

Betweenness centrality quantifies the number of times a port acts as a bridge along the shortest path between two other ports

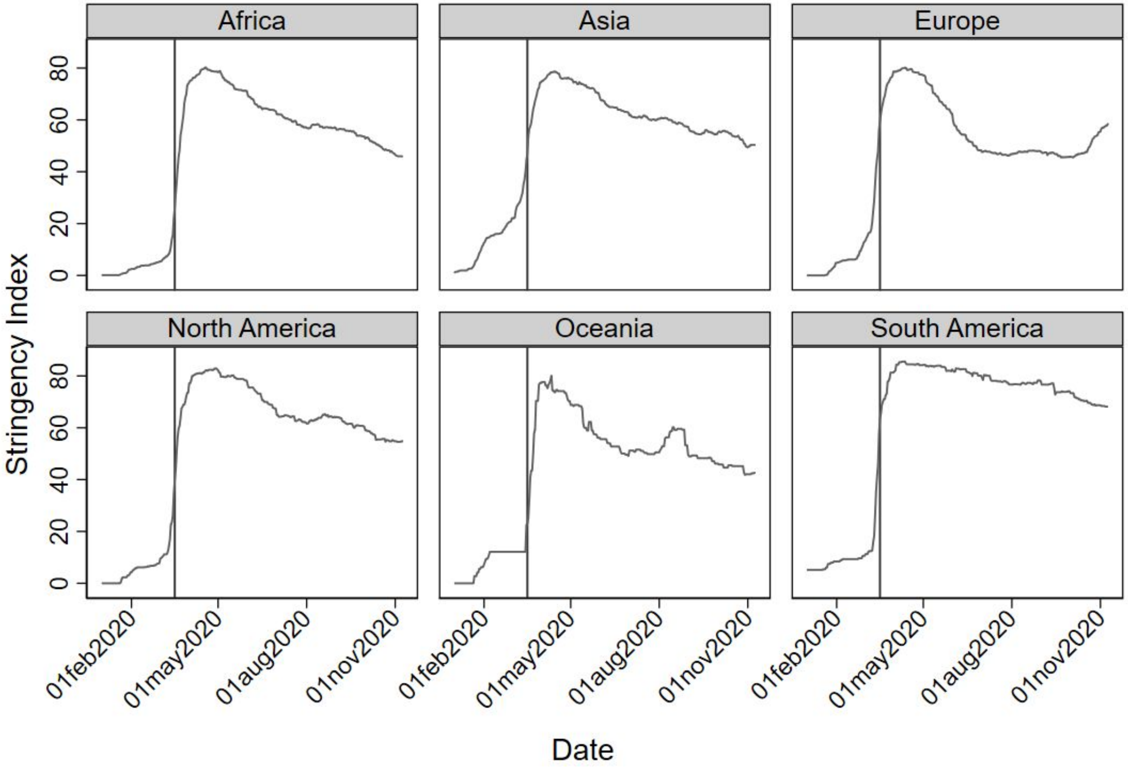


Tapiocozzo Red (High score) vs Blue (Low score)

Methodology (3)

Evolution of the Covid-19 policy stringency index during 2020

(Source: Thomas et al., 2021)



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Methodology (4)

- Regression analysis:
  - **Impact of Covid-19 outbreak on port hierarchies at the continent level:**

$$\begin{aligned}&\mathrm{Log}(\text{Concentration index of port weighted degree in continent } C \text{ during week } w)\\ &\qquad = \alpha_C \times 1_{Covid,C,w} + \text{Month-Continent FE} + \text{Continent Linear time trend}\end{aligned}$$

  - **Impact of Covid-19 outbreak on port weighted degree depending on the <u>clustering</u> and <u>weighted degree</u> of the ports before the outbreak:**

$$\begin{aligned}&\mathrm{Log}(\text{Weighted degree of port } p \text{ located in country } c \text{ during month } m)\\ &= \alpha \times 1_{Covid,m} + \alpha_{clust.} \times 1_{Covid,m} \times B_{p,clust.} + \alpha_{wdeg.} \times 1_{Covid,p,m} \times B_{p,wdeg}\\ &\qquad + \text{Month-Country FE} + \text{Port FE}\end{aligned}$$

Results (1)
Global decrease in port connectivity, but some ports resisted better (Mostly in developing economies)

	Port, Country	Betweenness centrality variation rate
1	Taichung, TW	93.2%
2	Gwangyang, KR	89.3%
3	Jintang, CN	82.1%
4	Houston BC, US	77.3%
5	Mundra, IN	74.7%
6	Hamad, QA	68.6%
7	Port Qasim, PK	66.9%
8	Paranagua, BR	61.8%
9	Bangkok, TH	52.2%
10	Salvador, BR	51.6%

Results (2) - Effects of Covid-19 national mitigation measures on continental port hierarchies

Variables	(1) Gini	(2) Gen. Ent. 0	(3) Gen. Ent. 1	(4) Atkin. 1	(5) Atkin. 2
Covid*Europe	-0.011***	-0.034***	-0.033***	-0.014***	-0.004
Covid*Africa	-0.032**	-0.084**	-0.090**	-0.051**	-0.023**
Covid*Asia	0.006***	0.064***	0.008	0.022***	0.012***
Covid*North America	0.021**	0.039*	0.048**	0.022*	0.009*
Covid*South America	0.000	0.011	0.007	0.006	0.001
Covid*Oceania	0.027*	0.074	0.069*	0.045	0.021
Observations	570	570	570	570	570
R-squared	0.973	0.967	0.977	0.953	0.898

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Results (3) - Effects of Covid-19 on ports' throughput depending on their connectivity

	Whole world				
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
	(1)	(2)	(3)	(4)	(5)
Covid	-0.191***	-0.193***	-0.191***	-0.196***	
Covid*Clustering	0.237***	0.240***	0.238***	0.238***	0.271***
Covid*Weighted Deg.	0.337***	0.346***	0.328***	0.327***	0.232
Observations	13,932	13,932	13,932	13,932	13,932
R-squared	0.013	0.015	0.055	0.055	0.282
Number of ports	647	647	647	647	647
Controls					
FE port	X	X	X	X	X
FE year*port				X	
FE season	X				
FE season*continent		X			
FE season*country			X	X	
FE month*country					X

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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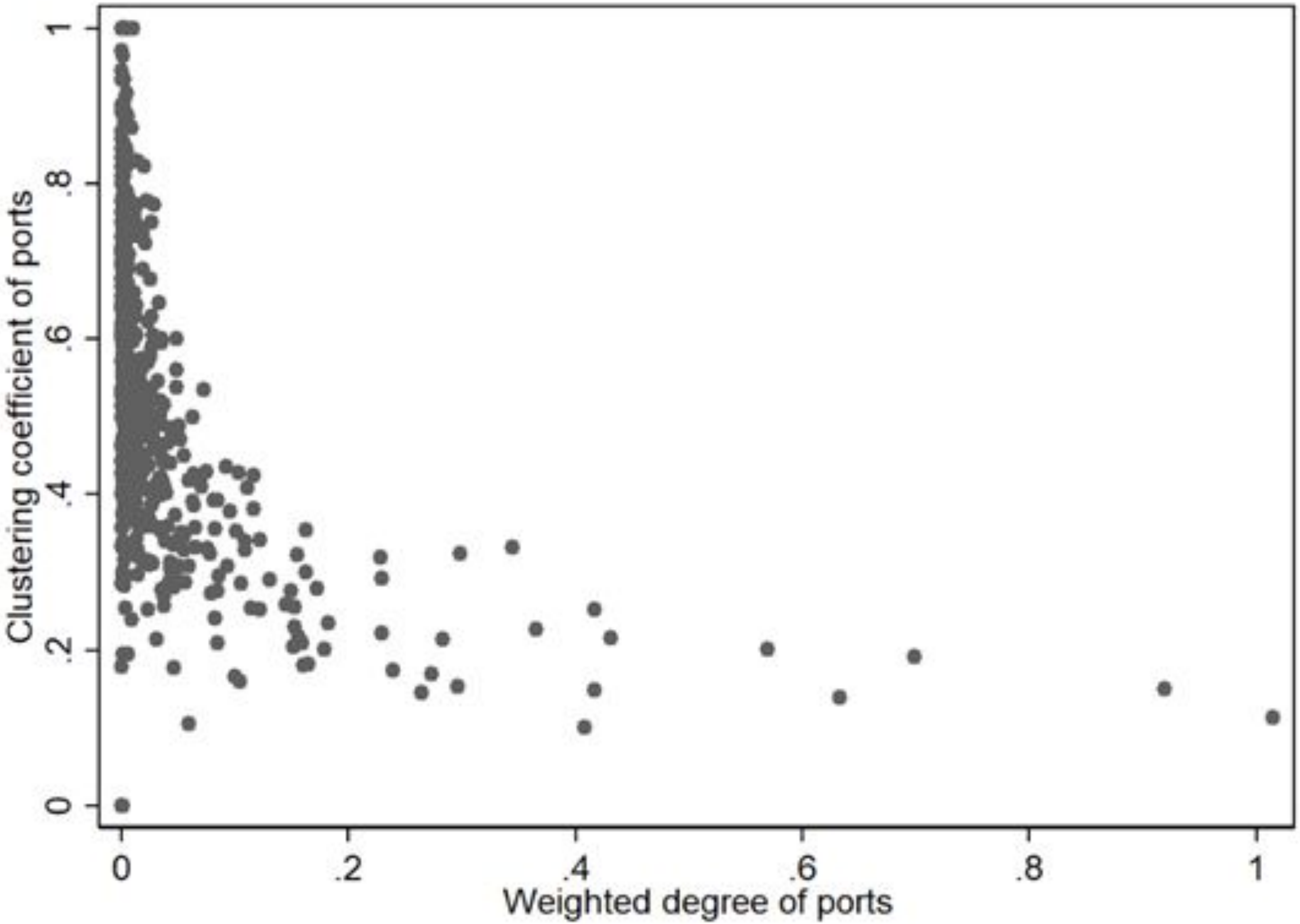
Results (4) - Remark

Distribution of ports depending on their clustering coefficient and weighted degree



Results (5)
Effects of Covid-19 national mitigation measures

- **The impact on port hierarchies (degree) at the continental level is confirmed**
  - However it differs depending on the regions
    - Europe and Africa: Mitigation measures favored deconcentration of port calls
    - Asia and North america: Mitigation measures favors concentration

- **Ports with certain characteristics have better resisted:**
  - Large ports
  - Small ports highly interconnected with their neighbours (high clustering coefficient)

Results (6) - Robustness

- **Robust when:**
  - computing Gini of inequalities between countries' throughput at the continental scale (instead of between ports' throughput)
  - adding other connectivity indices (betweenness centrality, average size of ships…)
  - considering each continent separately (generally significant)

Conclusion and implications

- This work has studied changes in the containerized network before/during Covid-19 (first 9 months)
- Overall decrease in port connectivity (several network indicators)
- Covid-19 mitigation policies impacted port hierarchies differently depending on the regions (Asia, North America vs Europe, Africa)
- Globally, large ports and small but densely interconnected ports resisted better
- Small hubs seem particularly vulnerable (port development projects mainly oriented to transshipment should be carefully considered)

Thanks!

Questions, comments?

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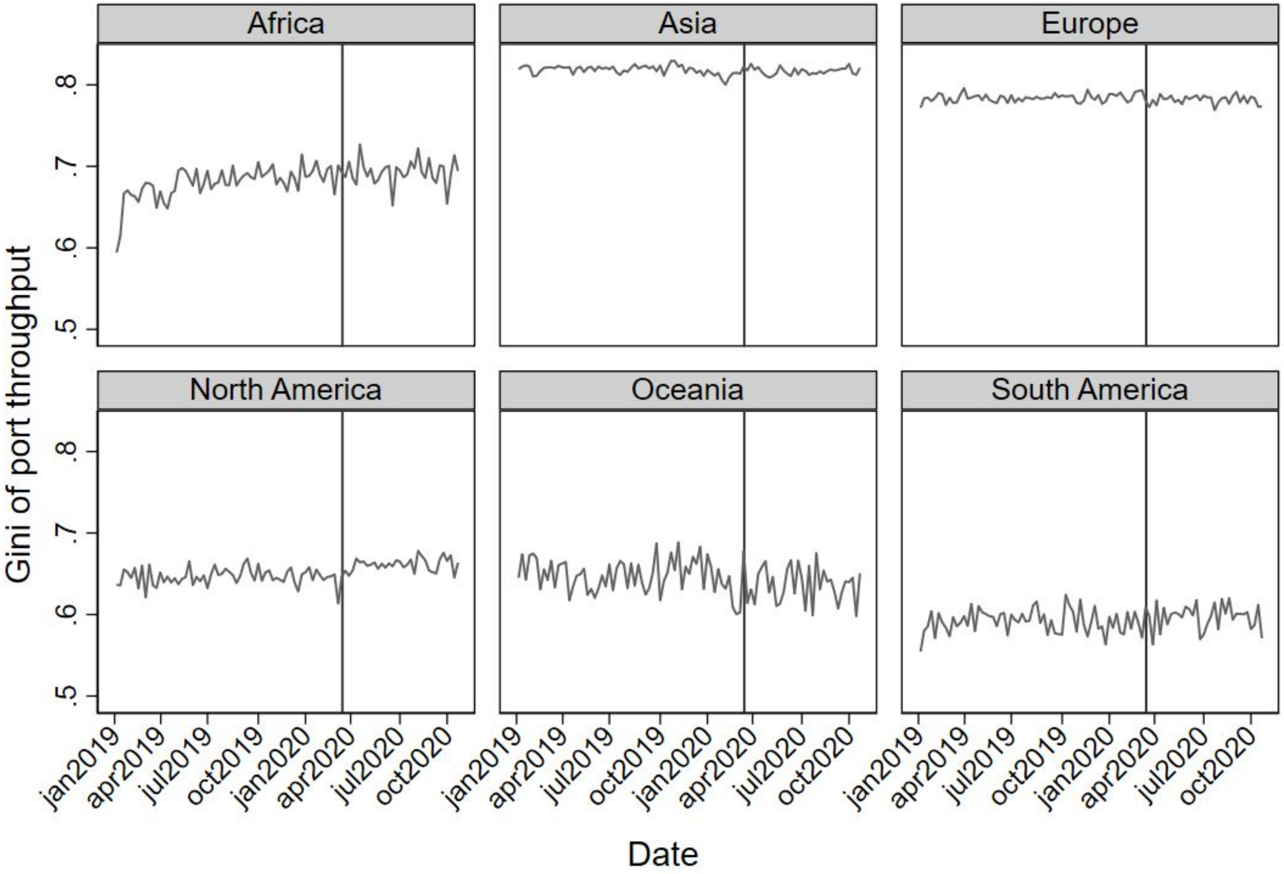
Appendix (1)

Gini coefficient measuring inequalities in ports' throughputs (i.e. ports' weighted degrees measured in number of TEUs) at the regional level



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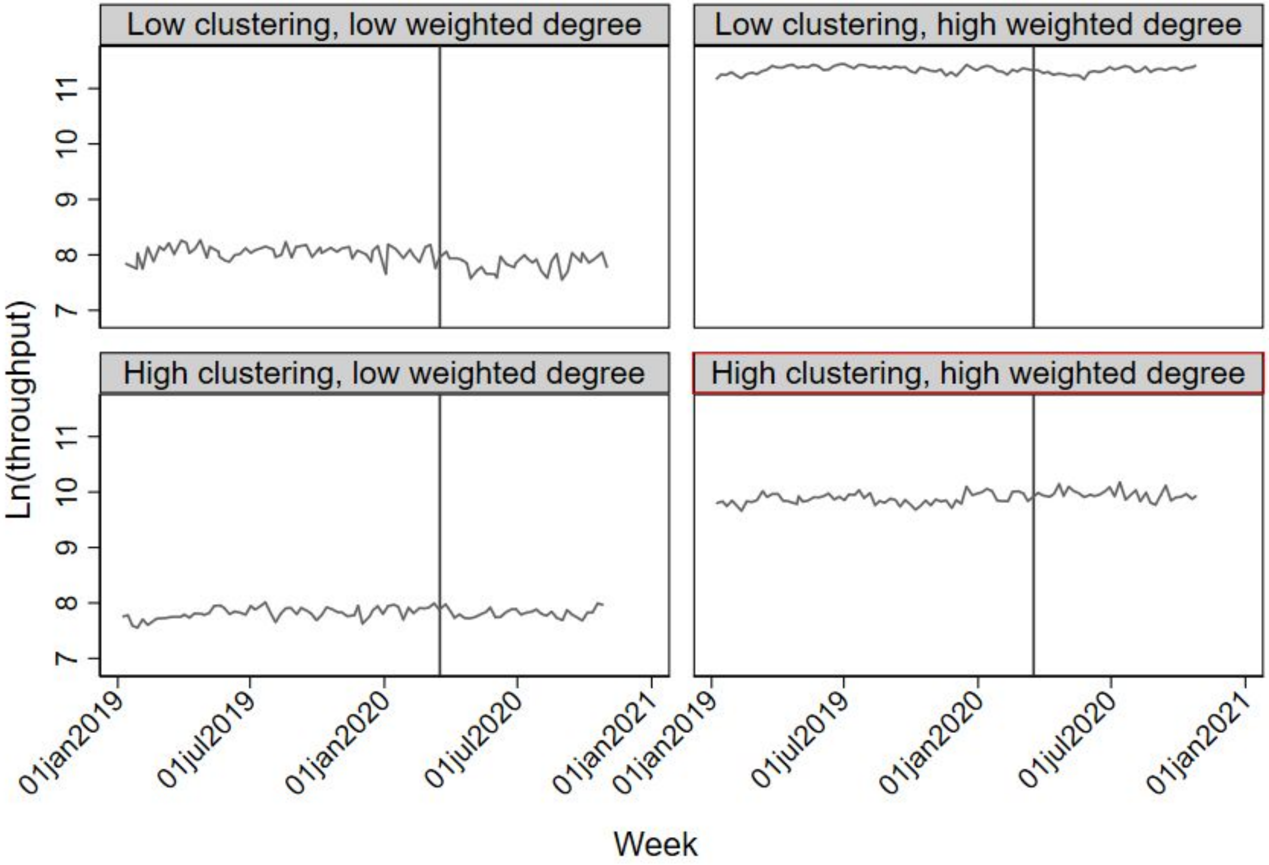
Appendix(2)

Evolution of the logarithm of port throughput (measured in number of TEUs)



Appendix(3)

Diff-in-diff estimation of the impact of Covid's crisis on port throughput, depending on the network characteristics of ports (clustering coefficient and weighted degree) in Europe, Asia and the other regions

Geographic zone	Europe		Asia		Other continents	
	Spec. 4	Spec. 5	Spec. 4	Spec. 5	Spec. 4	Spec. 5
	(1)	(2)	(3)	(4)	(5)	(6)
Covid	-0.266***		-0.265***		-0.103	
Covid*Clustering	0.348***	0.354***	0.384**	0.424**	0.041	0.088
Covid*Weighted Deg.	0.801**	0.967**	0.343**	0.255	0.372	0.382
Observations	3,799	3,799	4,959	4,959	5,174	5,174
R-squared	0.049	0.202	0.047	0.252	0.087	0.412
Number of ports	174	174	233	233	240	240

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Appendix(4)

Geographical distribution of ports depending on their clustering coefficients (grouped by quintiles)

Clustering coefficient		Africa	Asia	Europe	North A..	Oceania	South A..	World
(Low)	1st quintile	12%	19%	20%	**30%**	**28%**	15%	20%
	2nd quintile	21%	16%	20%	25%	16%	31%	20%
	3rd quintile	25%	19%	23%	17%	28%	25%	22%
	4th quintile	25%	19%	23%	7%	13%	13%	18%
(High)	5th quintile	16%	**26%**	14%	**22%**	16%	15%	20%