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Supply Chains and Port Congestion Around the World

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ABSTRACT: Rising prices and reports of empty shelves in major economies have drawn attention to the functioning of supply chains that normally operate smoothly in the background. Among the issues, the long delays that port congestion may have caused in delivering goods to consumers and firms have been gathering increasing attention. We shed light on these issues leveraging a unique data set on maritime transport. Two main features emerge. First, at the world level, we find that shipping times jumped upwards as soon as the COVID crisis hit, and after a marked acceleration from end-2020, delays surpassed 1.5 days on average by December 2021 – or roughly a 25 percent increase in global travel times. The estimated additional days in transit for the average shipment in December 2021 can be compared to an ad-valorem tariff of 0.9 to 3.1 percent. The midpoint of this range is approximately equal, in absolute value, to the global applied tariff reduction achieved over the 14-year period from 2003 to 2017. Second, not all congestion appears related to increased demand. Many ports, especially since mid-2021, exhibit longer wait times despite handling less cargo than pre-pandemic. Infrastructure upgrading is therefore likely a necessary, but not sufficient condition for building resilience during a crisis where other factors (such as labor shortages) may also become binding.

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I. Introduction

Seaports are hubs in the global trade network where supply chain bottlenecks can become very visible to the naked eye. Rising prices and reports of empty shelves in the United States have drawn attention to the functioning of supply chains that normally operate smoothly in the background. Among the issues, the press and industry groups repeatedly highlighted the long delays that port congestion causes in delivering goods to consumers and firms. This paper provides stylized facts on the extent and geographic distribution of port delays by leveraging a unique data set on maritime transport.

Our dataset is based on Cerdeiro, Komaromi, Liu and Saeed (2020; CKLS henceforth) and it provides a granular picture of world seaborne trade by tracking virtually all cargo ships in the world. CKLS develops algorithms to translate ships' radio messages from the Automatic Identification System (AIS) into port-to-port voyages and corresponding trade volume estimates.

The voyage data confirm that ports have contributed to increased trade frictions in the global transport system since the onset of the pandemic. The entire distribution of international travel times has shifted to the right compared to the pre-pandemic benchmark. Shipping times jumped upwards as soon as the covid crisis hit, and after a marked acceleration from end-2020, the delays surpassed 1.5 days on average by December 2021. Considering that global average travel times consistently hovered between 6 and 6.5 days from 2016 to 2019, the additional port delays by end-2021 amounted to a roughly 25 percent increase. Using calculations from the literature, the estimated additional time in transit for the average shipment in December 2021 is comparable to a global ad-valorem tariff of 0.9 to 3.1 percent. The midpoint of this range is approximately equal, in absolute value, to the global applied tariff reductions achieved over the 14-year period from 2003 to 2017.

Although port congestion has affected a wide range of countries, there is substantial geographical variation in the extent and persistence of delays, with China and the U.S. being the most affected. An analysis of port-level cargo throughput and turnaround times suggests that port congestion is driven by a complex combination of demand pressures and supply factors. Although the rapid demand recovery in the U.S. and other advanced economies has clearly put pressure on port

services across the board, there is evidence that supply factors have created significant bottlenecks for many ports.

The rest of the paper is organized as follows. Section II broadly describes the construction of the seaborne trade dataset. Section III introduces the methodology to estimate the level of congestion and delays at the port level. Section IV presents stylized facts about the extent and geographic distribution of port congestion and provides suggestive evidence for the presence of significant supply bottlenecks. Section V concludes.

II. High-frequency world seaborne trade data set[1]

More than 80% of merchandise trade by volume and 70% by value is carried by the world vessel fleet (UNCTAD, 2017). Much like airplanes and their transponders, for navigational safety purposes virtually all cargo ships in the world are required to carry a device commonly known as AIS (Automatic Identification System) that periodically emits a signal.[2] The radio messages emitted by these devices – which include information about ship type, position, speed, draught, etc. – are visible to nearby ships so as to avoid collisions, and are also collected by terrestrial receivers (if the ship is near a shore) and commercial satellites (if the ship is in the deep oceans).

CKLS show how different machine-learning techniques can be used to construct port-to-port voyages and estimates of trade volumes based on AIS data. We use their estimates that build on over two billion AIS messages collected between January 1st 2015 and December 31st 2021. To make this paper self-contained, we briefly illustrate here the process of going from the raw AIS messages to port-to-port volume estimates. The reader is referred to CKLS for further details.

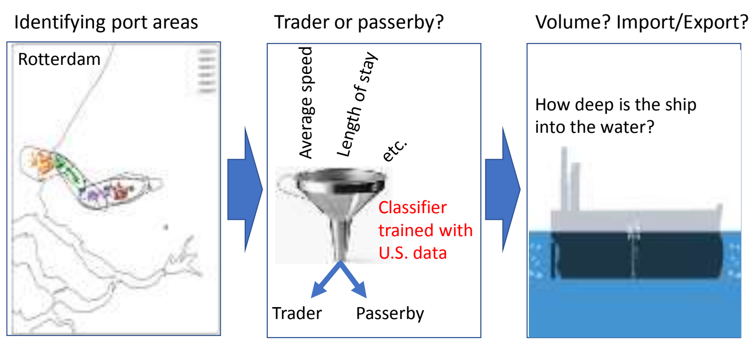
First, a spatial clustering algorithm is applied to all low-speed AIS messages reporting navigational status *anchored* or *moored* to detect areas on the map that are presumed to be ports. Using publicly available information, these areas are mapped to ports and to countries. Second, a random forest classifier is trained using official U.S. vessel-level entry records to tell us, for any

[1] For more details, see Cerdeiro, Komaromi, Liu and Saeed (2020) "World Seaborne Trade in Real Time: A Proof of Concept for Building AIS-based Nowcasts from Scratch," IMF Working Papers 20/57.

[2] While most ships send AIS messages with a frequency of 2-10 seconds, the data we use are down-sampled to the hourly frequency. The raw AIS data were collected by MarineTraffic.

ship stepping on any of these port areas, whether this visit is related to trade or if the ship was simply passing by. Finally, trade volumes are calculated on the basis of the ships' carrying capacity and the draught information contained in the messages, i.e., how deep the ship is into the water. The mapping of these volumes to imports, exports or intra-country trade is a function of the country where the previous and next ports are located, and the full sequence of draught values of the ship. The process is summarized in Figure 1.[3]

Figure 1. Construction of Port-to-Port Trade Volumes from AIS data



Notes: The Figure illustrates the end-to-end solution to go from raw AIS data to port-to-port trade volumes. See Cerdeiro, Komaromi, Liu and Saeed (2020) for full details.

The main interest in CKLS is to nowcast trade volumes at the country level. As a result, CKLS include an in-depth analysis of aggregated country-level estimates of trade volumes. In contrast, the analysis of port congestion and supply chain disruptions in the present paper requires the use of bilateral port-to-port travel times and voyage-level trade estimates. We therefore present here some stylized facts of the granular data that are relevant for our purposes.

The analysis in this paper focuses on certain ship types, such as container ships, general cargo ships and vehicle carriers, which play the most prominent role in manufacturing supply chains. That is, we do not include ships that are connected to commodity trade (e.g., tankers, bulk carriers) or leisure use (e.g., yachts, cruise ships). Similarly, we focus on international trade, so we drop all voyages where the origin and destination ports are in the same country.

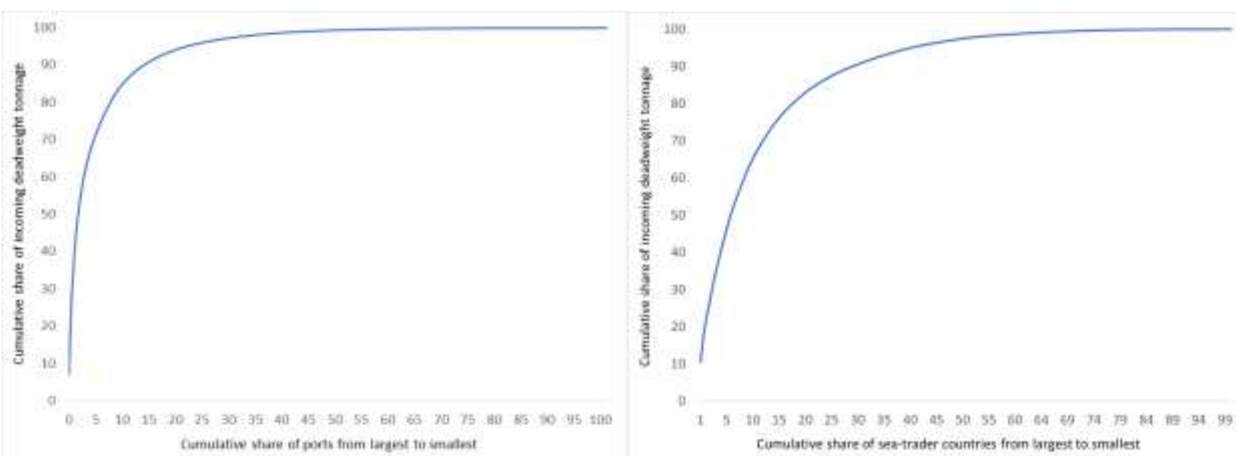
[3] The country-level aggregated trade volume estimates can be visualized at https://comtrade.un.org/data/monitor and downloaded at https://comtrade.un.org/data/ais.

The filtered dataset contains 1,634 seaports in 183 countries and territories. 4.5 percent of all origin-destination port pairs showed direct trade activity in the 2016-2021 period. Similarly, we observe trade for about 28 percent of the possible bilateral country pairs. This already suggests that most maritime trade is concentrated to some major ports and sea-trader nations.

Figure 2 shows that the size distribution of ports, measured by total incoming ship capacity, has very long tails. The top 30 ports account for more than half of total ship capacity and the top 100 ports manages over 75 percent. Similarly, there is a small set of countries that handle the overwhelming majority of incoming ships. The top 10 countries are responsible for processing almost half of seaborne trade and the top 25 approaches 75 percent (see Figure 2). The most important sea-trader countries are in Asia (China, Korea, Malaysia), followed by the US and some European countries (UK, Netherlands, Germany and Belgium). Not surprisingly, most of the largest ports are found in these countries, although Taiwan Province of China and the United Arab Emirates also host one port each from the top 10.

Figure 2. Distribution of port and countries by managed cargo capacity (Lorenz curves)

A) Ports **B) Countries**



Notes: Lorenz curves of estimated port size. The size (importance) of ports and countries is measured by the total deadweight tonnage of incoming ships.

III. Estimating port congestion

This section describes the steps to derive our measure of port congestion. This measure is based on the additional time that ships need to complete a trip between the same origin and destination ports compared to the pre-pandemic baseline. After applying the filters on ship type and international voyages, we proceed as follows.

First, we define the *travel time* between two ports to include the turnaround at the destination port. That is, the travel time is measured as the elapsed time between leaving the polygon of the origin port and leaving the polygon of the destination port. With this definition, the travel time includes three components: sailing between the two ports, waiting at anchorage before entering the destination port, and the cargo processing time (e.g., removing and loading containers) at the berth within the destination port.

Second, we use our identified ship voyages to calculate the weighted average travel time between all origin-destination pairs for each month. We use the cargo ships' deadweight tonnage, a measure of carrying capacity, as weights in the calculation. We can interpret the resulting number as the expected time it took in a given month to transport a random unit of cargo between two ports, including cargo handling at the destination.

Third, we define a pre-pandemic baseline travel time for each port pair as the 2019 average, weighted by ship capacity as described above. Then we calculate the deviation from this baseline to obtain the additional delays that ships encounter when moving cargo through these ports. We interpret these delays as a measure of congestion at the destination port, that is longer wait times at anchorage areas and slower cargo handling at the berth. This interpretation is justified by the reasonable assumption that actual sailing times between ports have not changed since the pandemic. After all, vessel physics largely determines how fast ships can go and we are mostly observing the same ships.

Fourth, the bilateral port-level delays can be aggregated as suitable, for example, by destination country, by origin country, or by country-pair, always using deadweight tonnage as weights to make sure smaller ships do not bias the results.

Finally, we can break down the additional delays into waiting at anchor outside the ports and longer processing time within the ports. Since we observe the time that ships spend inside the port polygons, we can implicitly back out the time at anchorage. We note that this decomposition

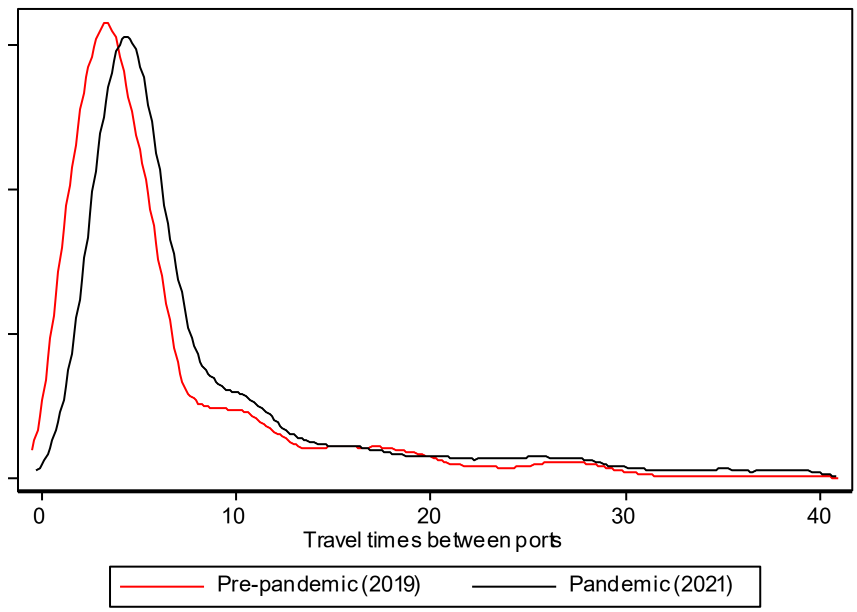
should be viewed as indicative or suggestive evidence because the delineation of the border between anchorage areas and core port areas is not always straightforward.

An important caveat about our indicator of port congestion is that it should be treated as a lower bound measure of port-level disruptions, especially when comparing its evolution over time. The reason is that the change in average travel times between port pairs incorporates the optimizing response of shipping companies and the importers and exporters they serve. For example, incoming shipments may be rerouted to less crowded ports with excess capacity, changing the composition of international voyages. Had those ships called at their original destination ports, they would have caused even more congestion ceteris paribus. Nevertheless, there are limits to this type of substitution especially for larger ships that require certain port infrastructure and water depth.

IV. Results

The data support the notion that ports have contributed to increased trade frictions in the global transport system since the onset of the pandemic. Suggestive evidence is provided by Figure 3, which plots the distribution of travel times for the pre-pandemic year 2019 (red line) and the year 2021 (black line). It is evident that the distribution shifted to the right, indicating that longer trips became the norm for cargo ships. Of course, this graph does not tell us whether these longer trips entail delays and congestion at seaports. The observed shift could be consistent with a scenario where trade migrated to port pairs that are farther away from each other, justifying the longer travel times. To draw more precise conclusions, we need to compare travel times between the same origin-destination pairs, as explained in our methodology section (Section III).

Figure 3. Distribution of travel times for international voyages

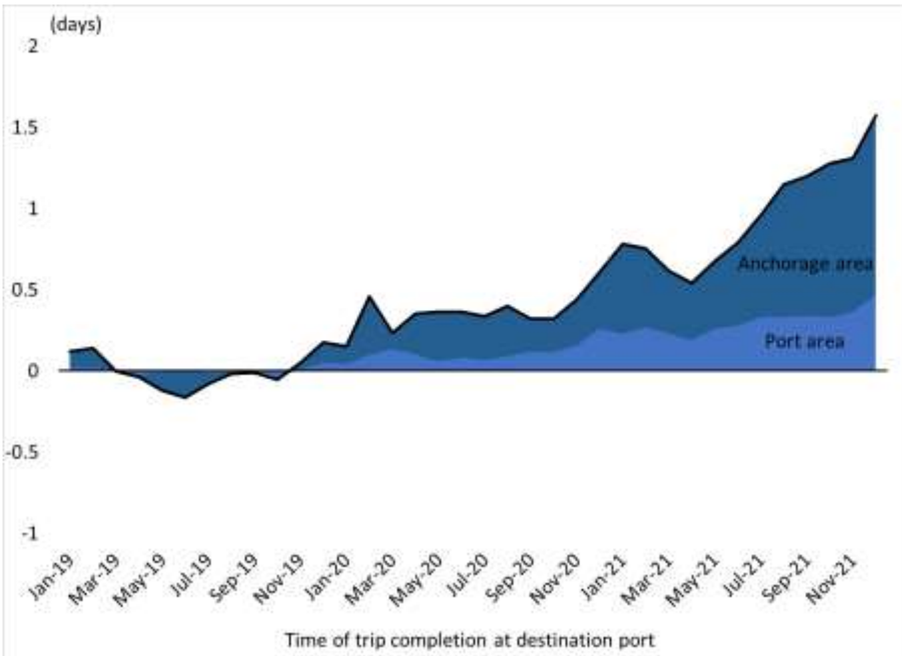


Notes: Kernel density estimates are weighted by the deadweight tonnage of ships that sail between the origin and destination ports.

Comparing travel times on the same routes, the data unambiguously reveal that ports did get more congested, and ships did face more delays, likely causing disruption in supply chains. The main result is illustrated by Figure 4 which shows our measure of average port congestion calculated across the global fleet's all international voyages. At the world level, shipping times jumped upwards as soon as the covid crisis hit, and after a marked acceleration from end of 2020 the delays surpassed 1.5 days on average by December 2021. Considering that global average travel times consistently hovered between 6 and 6.5 days from 2016 to 2019, the additional port delays by end-2021 amounted to a roughly 25 percent increase. Figure 4 also breaks down the slowdown around ports into two components. About two-thirds is attributable to ships waiting longer at anchor before entering the port, and one-third is caused by slower cargo processing at the berths.

Figure 4. Port delays compared to pre-pandemic baseline, world average

2019 average = 0



Notes: Average travel times along all international routes, in deviation to pre-pandemic (2019) times.

A back of the envelope calculation suggests that the estimated delays at seaports generate substantial welfare losses. One way to conceptualize port delays through the lens of gravity models is to imagine that the world has become a more distant place. More time spent in transit imposes significant costs that impede trade. For example, Hummels and Schaur (2013) estimated tariff-equivalents for each day in transit. Using their results for illustration, the estimated one and a half additional days in sea transit for the average shipment in December 2021 was comparable to an ad-valorem tariff of 0.9 to 3.1 percent.[4] The midpoint of this range is approximately equal,

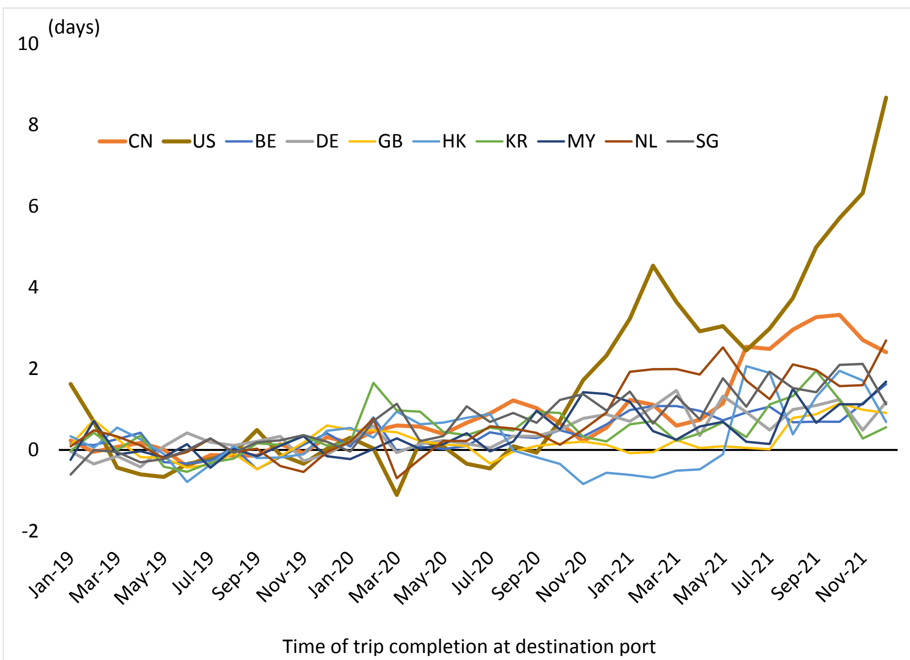
[4] The mapping of ships' additional travel time to a tariff equivalent requires some caveats. First, Hummels and Schaur (2013) derived their estimates comparing air and sea transport, and it is not guaranteed that similar parameters are applicable for sea transport that is delayed by a day. Second, importers may be able to plan around this additional friction to some extent (e.g., by changing their ordering practices) which is not the case for universal tariffs.

in absolute value, to the global applied tariff reductions achieved over the 14-year period from 2003 to 2017.[5]

Importantly, there is substantial geographical variation in port delays**.** The world average in Figure 4 is based on all international voyages, from short trips within Europe to trans-oceanic journeys between Asia and the Americas. Figure 5 presents the same calculations for the top 10 destination countries by incoming ship capacity. It is evident that although all major sea trader nations have experienced delays, the most severe port congestion is concentrated in the U.S. and China. The figure also reveals that port congestion has deteriorated and become more widespread in the second half of 2021.

Figure 5. Port delays compared to pre-pandemic baseline

top sea trading countries (2019 average = 0)



Notes: Change in average incoming travel times by destination port aggregated to country level.

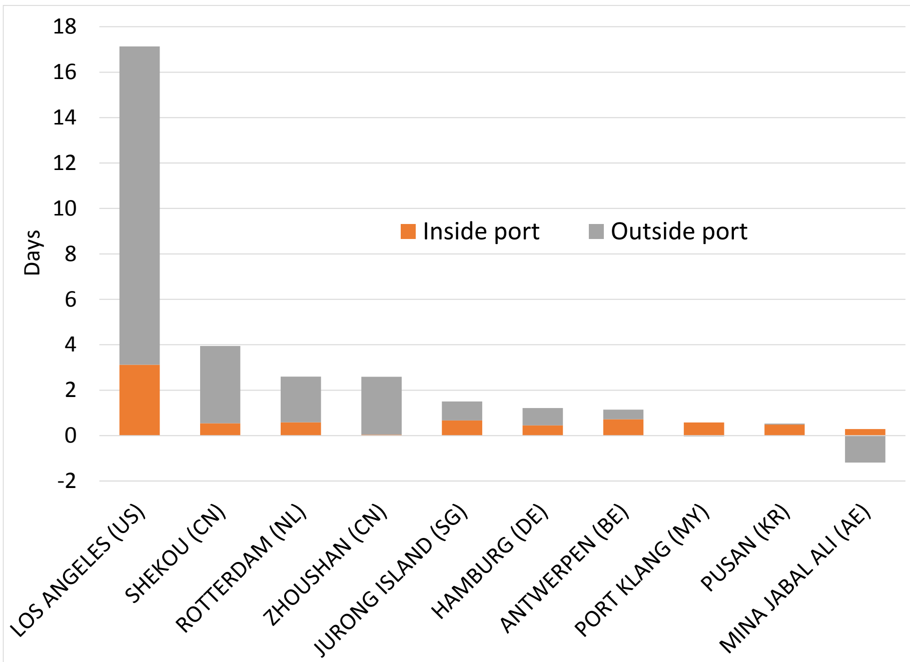
The variability in delays is also evident at the port level (Figure 6). The often-cited Los Angeles port is undoubtedly an outlier among major seaports both in terms of longer wait times at

[5] See global average of applied tariff rates at https://data.worldbank.org/indicator/TM.TAX.MRCH.WM.AR.ZS

anchorage and slower processing times at the berths. Slower turnaround times on the docks suggest that not only more ships are arriving at the port, but that supply bottlenecks, such as the stacking up of empty containers, prevent the efficient processing of incoming cargo.[6]

Figure 6. Port delays compared to pre-pandemic baseline

selected large ports (2021Q4)



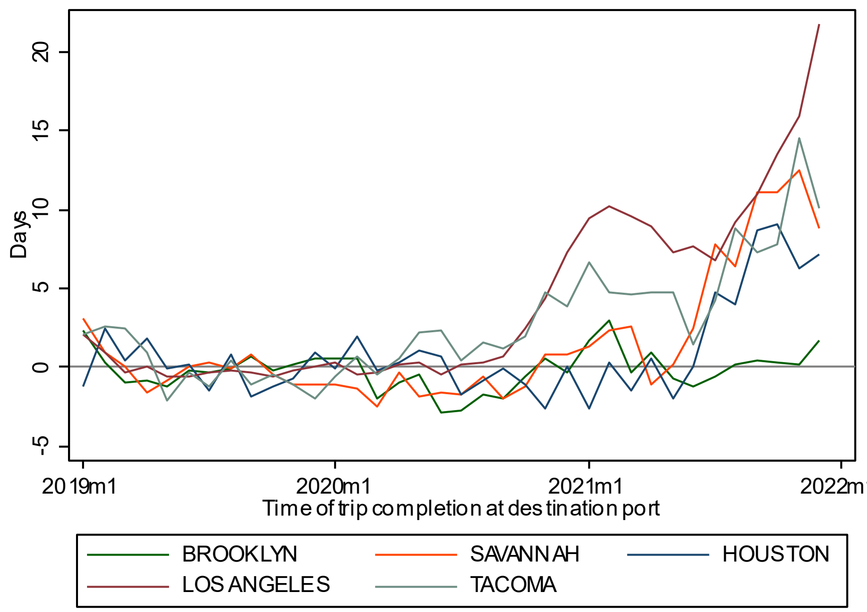
Notes: Change in average incoming travel times by destination port.

Port congestion is likely driven by a complex combination of demand pressures and supply factors. Most of the largest U.S. container ports show similar patterns of delays suggesting that the rebound of consumer spending is a common factor behind the congestion (Figure 7). On the other hand, whether rising demand translates into congestion also depends on the ports' pre-pandemic capacity utilization rate. Ports with excess capacity may be able to accommodate more cargo without increasing wait times for vessels. However, if a port handles less cargo with longer delays, it is suggestive of supply disruptions.

[6] Supply chain bottlenecks due to insufficient port investments in the US have been highlighted before. For example, the American Society of Civil Engineers assigned a B- rating to US port infrastructure and the Global Infrastructure Outlook (A G20 Initiative) estimates a $168 billion investment gap for US port infrastructure in the years to 2040.

Figure 7. Port delays compared to pre-pandemic baseline

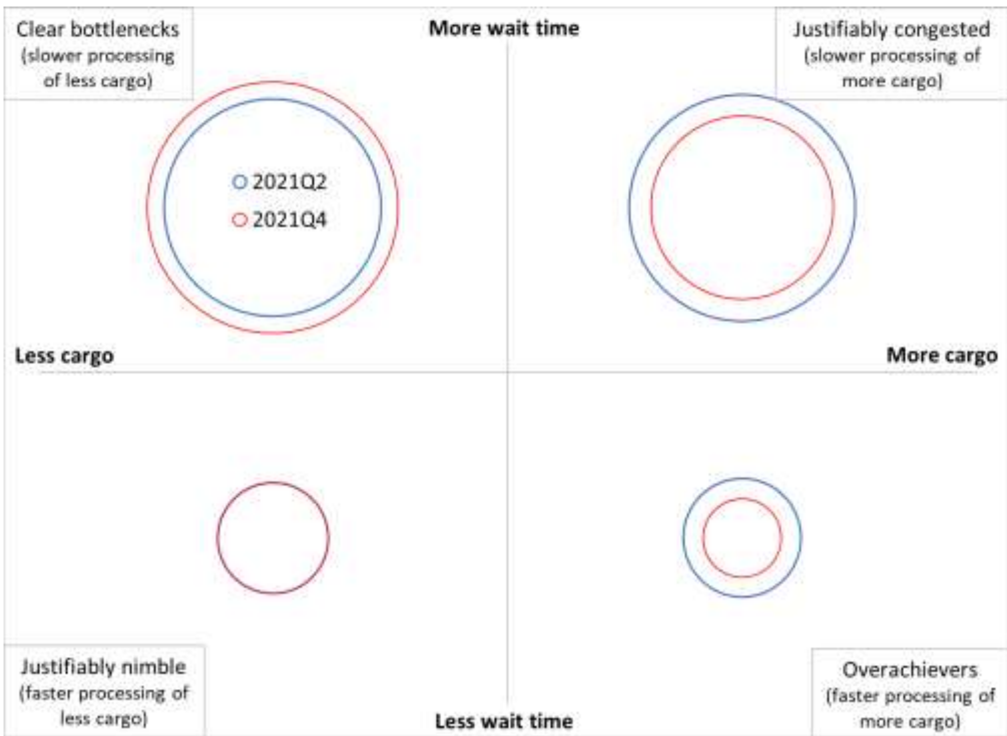
major U.S. ports



Notes: Change in average incoming travel times by destination port.

Figure 8 demonstrates that a significant part of global trade was handled by ports that fall into this supply-driven bottleneck category (upper left quadrant). For these ports, labor shortages, infrastructure weaknesses and backlogs from current or past covid restrictions likely play the decisive role. Moreover, this measure of supply disruptions shows a deteriorating trend in the second half of 2021 with more cargo captured by the group of less productive and more congested ports.

Figure 8. Shipping delays and incoming cargo capacity at the port level



Notes: The figure is based on the 150 largest seaports. The change in travel times and processed cargo is compared to the same quarter in 2019 at the port level. The size of the bubbles is proportional to the total processed cargo in each quadrant. However, the location of the bubbles within each quadrant is fixed and independent of underlying growth rates.

V. Conclusion

Rising prices and reports of empty shelves in major economies have drawn attention to the functioning of supply chains that normally operate smoothly in the background. Among the

issues, the long delays that port congestion may have caused in delivering goods to consumers and firms have been drawing increasing attention. We shed light on these issues leveraging a unique data set on maritime transport. Two main features emerge. First, at the world level, we find that shipping times jumped upwards as soon as the COVID crisis hit, and after a marked acceleration from end-2020, the delays surpassed 1.5 days on average by December 2021 – or roughly a 25 percent increase. The estimated additional days in transit for the average shipment in December 2021 can be interpreted as a global ad-valorem tariff of 0.9 to 3.1 percent under some assumptions. The midpoint of this range is approximately equal, in absolute value, to the global applied tariff reduction achieved over the 14-year period from 2003 to 2017. Second, not all congestion appears related to increased demand. Many ports, especially since mid-2021, exhibit longer wait times despite handling less cargo than pre-pandemic. Infrastructure upgrading is therefore likely a necessary, but not sufficient condition for building resilience during a crisis where other factors (such as labor shortages) may also become binding.

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