Rigidities in Transportation and Supply Chain Disruptions

Giulia Brancaccio*, Myrto Kalouptsidi†, Theodore Papageorgiou‡§

New York University, Harvard University, Boston College

January 2025

In this paper we provide a simple and intuitive story for supply chain disruptions driven by the rigidities in the transportation sector. Focusing on maritime shipping, we argue that the frequent macroeconomic shocks that shape demand for transportation, meet a highly inelastic supply curve for transportation services. The steepness is driven by equilibrium bottlenecks in ships (transportation agents) and ports (transportation infrastructure). This leads to highly volatile shipping prices and port congestion, affecting importers and exporters worldwide. We discuss how both global trade and inflation react to these costs, so that disruptions pass through to the entire economy.

Keywords: supply chain disruptions, transportation, infrastructure, ports, ships, congestion

*New York University, Stern School of Business, Kaufman Management Center 44 West 4th Street New York NY 10012, USA, giulia.brancaccio@nyu.edu

†Harvard University, Department of Economics, Littauer Center 124, Cambridge MA 02138, USA, myrto@g.harvard.edu

‡Boston College, Department of Economics, Maloney Hall 332, Chestnut Hill, MA, 02467, USA, theodore.papageorgiou@bc.edu

§We gratefully acknowledge financial assistance from the NSF Award SES-231533-231534-231535, as well as the NBER Transportation Economics in the 21st Century Grant.

1 Introduction

International trade and growth are founded on reliable transportation and infrastructure. In recent decades, these services have appeared to operate seamlessly in the background of an increasingly interconnected world. Yet, as demonstrated in a dramatic way during the COVID-19 Pandemic, transportation, perhaps invisible to most until then, can cause great disruptions to our daily lives. In 2021, shipping prices more than doubled, port congestion rose by 45% (Brancaccio et al., 2025), and lead times for the delivery of inputs in the supply chain almost doubled (Alessandria et al., 2023); at the same time, the world suffered notorious shortages of goods, accompanied by a climbing inflation. For months, supply chain disruptions had been a frequent headliner in the press globally. Why does the transportation sector have the potential for such great disruption?

This paper combines recent work on transportation and infrastructure to provide a simple and intuitive answer to this question. We argue that, although the disruptions experienced during the COVID-19 Pandemic were an extreme event, it was neither the first nor the last time that the transportation sector displayed high volatility. In fact, transportation markets are inherently volatile. This is because demand for transportation is subject to local and global macroeconomic shocks, while, as we explain extensively in this article, supply is inelastic and steep. Then, we argue that this volatility matters, because trade and prices do respond to changes in transportation "inputs", such as shipping prices and port congestion.

We focus on oceanic shipping and ports, which are responsible for more than 80% of total trade in goods. At the same time, out of the average of 55 days required to deliver production inputs (Alessandria et al., 2023), more than half is time spent in ships and ports; in other words, even in normal times maritime transportation alone accounts for a substantial fraction of lead times in sourcing. That said, almost everything discussed in this paper applies to other modes of transportation, such as trucking, airlines and airports, as well as trains; although there are substantial operational differences among modes, the core economic mechanisms discussed here apply broadly.

2 Volatility of the Transportation Sector

Shipping cycles have been notorious for centuries, at least since the time of steam ships (Stopford, 2009). A simple way to see this is by looking at shipping prices. In Figure 1 we plot three freight rate indices: the Baltic Dry Index, tracking freight rates for dry bulk commodities, mainly raw materials such as coal, grain and iron ore; the Alphaliner Charter Index tracking container freight rates; and the Baltic Exchange

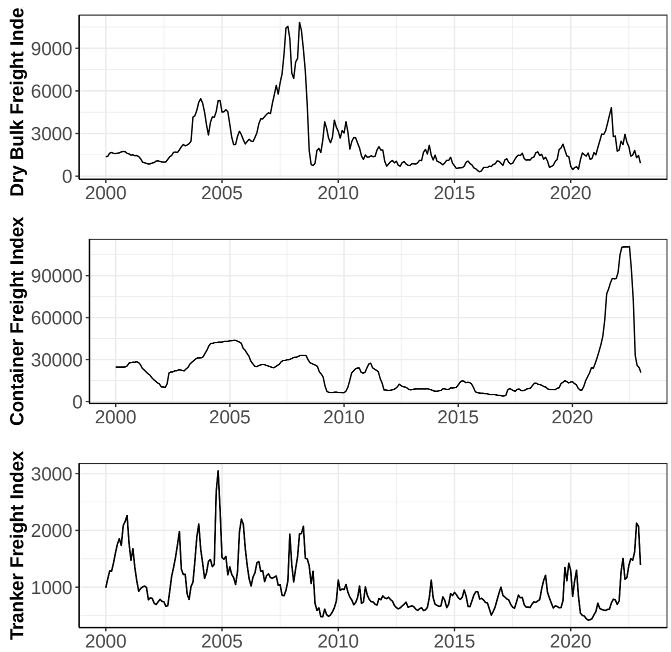

Figure 1: The top graph plots the Baltic Dry Index (BDI), which tracks the daily freight rates for dry bulk commodities, such as grain, coal and iron ore. The middle graph plots the Alphaliner Container Freight Index, which tracks the daily charter rates for containers (mostly relevant for manufacturing). The bottom graph plots the Baltic Exchange Dirty Tanker Index, which tracks the daily freight rates for (crude) oil tankers.

Dirty Tanker Index tracking (crude) oil tanker freight rates. It is immediately obvious that the volatility of freight rates is enormous.[1]

The COVID-19 disruption is clearly visible and large. Interestingly, however, it is not incomparable to other recent disruptions. For instance, in the case of bulk carriers, it is on par with, and in fact mellower than, the dramatic boom and bust of 2006-2008. In the mid-2000s, a rapid growth of raw material imports (a major demand shock), particularly in China, led to sustained increases in freight rates and a seven-fold surge in the new ship backlog between 2003 and 2008. The Great Recession in 2008 led to an idling of the existing fleet, while another 70% of that fleet was still scheduled for delivery by 2012 (Kalouptsidi, 2014). At the time, this was considered one of the most dramatic shipping cycles in history.

Why is shipping so volatile? The volatility is due to the combination of (i) a highly volatile demand for transport services, driven by macroeconomic shocks; and (ii) a highly inelastic supply of transport services. Demand volatility is driven by local and global macroeconomic shocks. In addition to regular macroeconomic fluctuations, prominent examples include the war in Ukraine, the Great Recession of 2008,

[1]Unless otherwise specified, all statistics and graphs in the remainder of this paper are produced based on data for dry bulk carriers, primarily from AXS Marine. Dry bulk carriers transport homogeneous and unpacked goods, such as iron ore, grain, coal, and steel for individual shippers on non-scheduled routes. Tankers carry chemicals, crude oil, and other oil products and operate in a similar fashion. Containerships carry containerized cargo from different shippers in regular port-to-port itineraries. As these types of ships carry entirely different commodities, they are not substitutable and can thus be thought of as separate markets (that are nonetheless highly correlated in the timeseries).

and catastrophic weather events. The other key ingredient that contributes to the disruptive nature of transportation, is its steep supply, as we discuss below.

3 Transportation Capacity Constraints and the Steep Supply Curve

The supply of transportation services is inflexible because of the rigid capacity constraints facing (i) ships; and (ii) ports. We next discuss each of these two sets of constraints in detail.

Ship Bottlenecks Several factors constrain the short- and long-run supply of ships. In the short-run, a ship has a given carrying capacity, and is constrained in terms of the number of trips it can execute every year. The maximum number of trips depends on the travel distance of these trips, as well as the time spent at ports. For instance, dry bulk ships perform trips that last on average three weeks (Brancaccio et al., 2020); time at port is an additional 22% of that at each end. In addition, even though a trip can be performed at different speeds, since the cost of fuel is convex (consumption is proportional to the cube of the vessel's speed (Stopford, 2009; Kalouptsidi, 2014) ships have a limited ability to adjust speed. Thus, when demand is high, even if no ships are idle, there is an upper bound to the number of trips they can execute (see for instance Brancaccio et al. (2025) for a discussion of how ship constraints amplify traditional trade shocks). In the end, a ship performs between eight and seventeen trips per year, depending on these factors, as well as the level of aggregate demand and the specifications of the vessel.

A series of easily identifiable shocks to this constraint have illustrated recently the large impact of these rigidities, such as the blockage of the Suez canal by the megaship Ever Given, the Houthi attacks in the Red Sea, and the drought at the Panama Canal. In all these cases, ships had to take longer trips; for instance, Figure 2 shows that following the beginning of the Houthi attacks in the Red Sea, the duration of trips from Europe to China increased by 30% as ships decided to avoid the Suez Canal for safety reasons. The increase in distance leads to both higher costs associated with the ships being used for more days, but it also limits the total quantity of goods that can be transported, as the existing supply of ships can now perform fewer trips.

In addition to these short-run constraints, new ships are not built in a day. It takes at least two years to build a ship, and construction times can also change over the cycle: shipyards are themselves capacity constrained due to their limited number of shipbuilding docks, and in periods of high demand queues accumulate and shipyards offer longer build times (for instance during the 2006 boom, time to build almost doubled). These leads in construction severely constrict the ability of new ship supply to

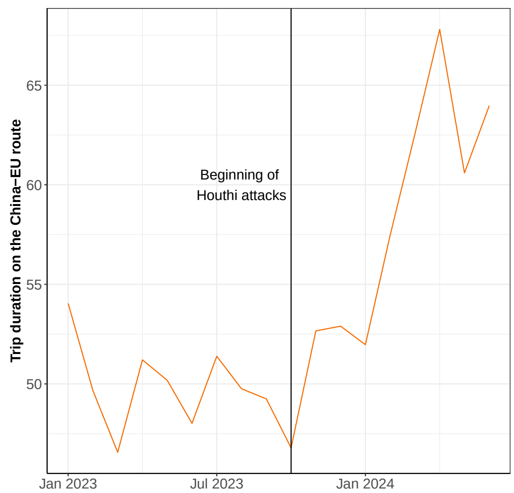

Figure 2: Increase in average trip duration in days on the China-EU route following the beginning of Houthi attacks in the Red Sea. Source: AXS Marine.

respond to demand shocks contemporaneously (Kalouptsidi, 2014).

That said, even if ships were built instantly, one should not expect ship supply to increase immediately following an increase in demand. Ships are long-lived assets; they are not scrapped until a few decades after their construction. This makes the investment decision to buy a new ship a long-term one: shipowners will not invest in new ships unless they believe that the demand increase is to be sustained in the medium to long-run, since they compare the lifetime expected profitability of the ship to its current cost (see Kalouptsidi, 2014; Dunn and Leibovici, 2024).

In summary, the supply of ships is constrained by the number of available vessels and their maximum capacity, and this depends on a multitude of factors that are determined in equilibrium, such as the number of trips executed at specific speeds, the distance that needs to be travelled, the lead times dictated by shipyards, and the long-run entry decisions of shipowning firms.

Port Bottlenecks Ports are maritime facilities where ships can load or discharge cargo. They are a crucial node of transportation infrastructure and constitute important bottlenecks in the logistics chain. We argue here that port capacity constraints pose significant restrictions to the supply of transportation services and amplify the systemic impact of even small shocks (Brancaccio et al., 2025). First, ports restrict the amount of goods that can enter a country. A port's infrastructure (berths, cranes, storage, etc.) rigidly determines how much cargo it can handle each period; in periods of high demand, ports might be unable to process the tonnage necessary to meet demand, possibly leading to shortages of goods and delays in the importing countries, as well as high prices.

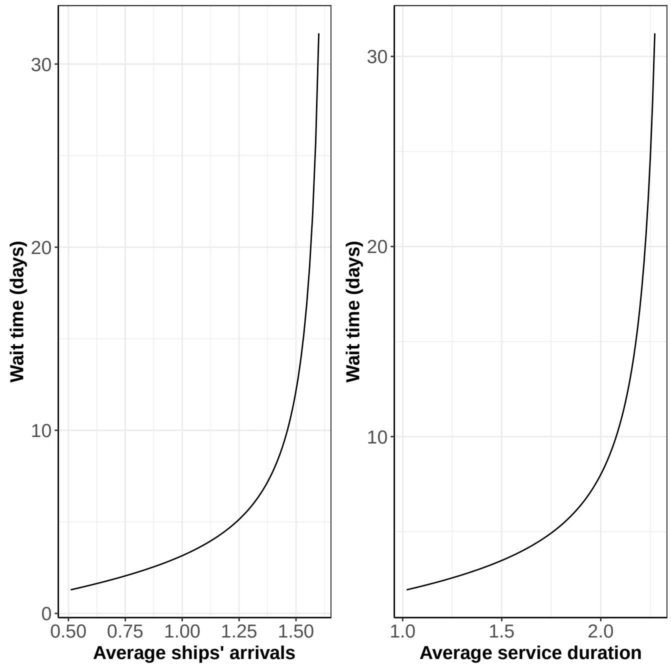

Figure 3: The left panel plots wait time as a function of the mean number of ship arrivals. The right panel plots wait time as a function of the mean service time duration. The graphs are generated by simulation of an M/M/c queueing model, using the average service time, arrival rate and capacity of ports.

Second, limited port capacity can lead to port congestion, which increases the time spent at the port, effectively reducing ship supply: when stuck at port, a ship is not available to offer transportation services. The longer the queues at the port, the fewer ships are available. It is thus not a surprise that time port (or port congestion), which captures both of these effects, is followed by practitioners, academics, policymakers, and the press.

Ships, even during normal times, spend a substantial portion of their trip at port. Time at port for dry bulk ships was on average 6 days between 2014 and 2024, which amounts to more than 40% of the trip duration, with massive dispersion over both time and space. As is well known, time at port exploded during the COVID-19 pandemic, almost doubling in several parts of the world. For the average port, the standard deviation over time was 4.30 days over the last ten years.[2,3]

Increased time at port captures both the limited capacity of ports to handle goods, but also the effective reduction in ship supply, which contribute to the disruptive nature of the transportation sector. A natural question is therefore, how is time at port determined?

[2]These port delays have large direct costs on importers and exporters in terms of freight and inventory management. Indeed, this time at port has a direct cost of holding the vessel, which, for dry bulk, in 2023 amounted to $14,000 per day on average; however, this is only a crude lower bound. In Brancaccio et al. (2024), we provide a structural model to quantify the overall cost of port congestion, and we find that it is significantly larger than the direct cost alone.

[3]There is also remarkable dispersion across space: ships wait on average as much 9.14 days in African ports and as little as five days in European ports, and for the average month the cross-sectional standard deviation in time at port is 6.25 days.

Time at port consists of the service time, which amounts to mostly cargo handling, plus any wait time spent in the queue. Following standard queuing theory models (such as the widely used M/M/c model), time at port is a function of (i) service time; (ii) port capacity, which can be thought of as the number of ships the port can simultaneously handle; and (iii) ship arrivals, which reflect demand for port services. In particular, service time affects time at port not only directly, but also through the wait time, since faster service time of the ships ahead imply that the queue moves faster. Port capacity directly affects wait time, since larger ports can handle more ships for a given level of demand. And conversely, more arrivals at a port, holding capacity and service time fixed, imply higher wait time. See Brancaccio et al. (2024) for more details.

This formulation allows us to understand the impact of different disruptions on time at port. In particular, the inherent nature of port operations make the wait time extremely susceptible to shocks to ship arrivals and service time, so that even a small shock has a large impact if it hits at the wrong time. To see this, Figure 3 plots how wait time depends on the expected number of ship arrivals and the expected duration of service. In periods with low average demand or service time, wait time is fairly low: it is likely that the port is not at capacity, so that an arriving ship immediately begins service. Increases in the service time or arrivals do not initially change time at port much, since the probability that the port is full remains low. As ship arrivals or service time further increase, the probability a ship has to wait becomes higher and average time at port goes up. After a certain point, further increases lead to a situation where the port's ability to service ships cannot keep up with new ship arrivals and the queue explodes.

The above analysis suggests that even small shocks can cause large increases in port congestion if they hit when the port is already strained. One such type of shock would be disruptions to service time, i.e. events that affect the ability of the port to quickly turn around ships. This includes strikes, crane breakdowns, or more extremely, port closures and personnel restrictions such as those placed during the COVID-19 Pandemic, extreme weather events, as well as other extreme situations (e.g. the war in Ukraine, or the bridge collapse in the port of Baltimore in March 2024). Similarly, a demand shock can increase ship arrivals and overwhelm ports that are already operating close to capacity.

To provide a few examples, the first panel of Figure 4 displays the change in service time in Ukrainian ports, which are major exporting ports for grain, after the start of the war in February 2022. The second panel illustrates congestion at Port Hedland, Australia, one of the world's largest exporting ports, following the landfall of Cyclone Veronica in March 2023, which caused significant damage to the port,

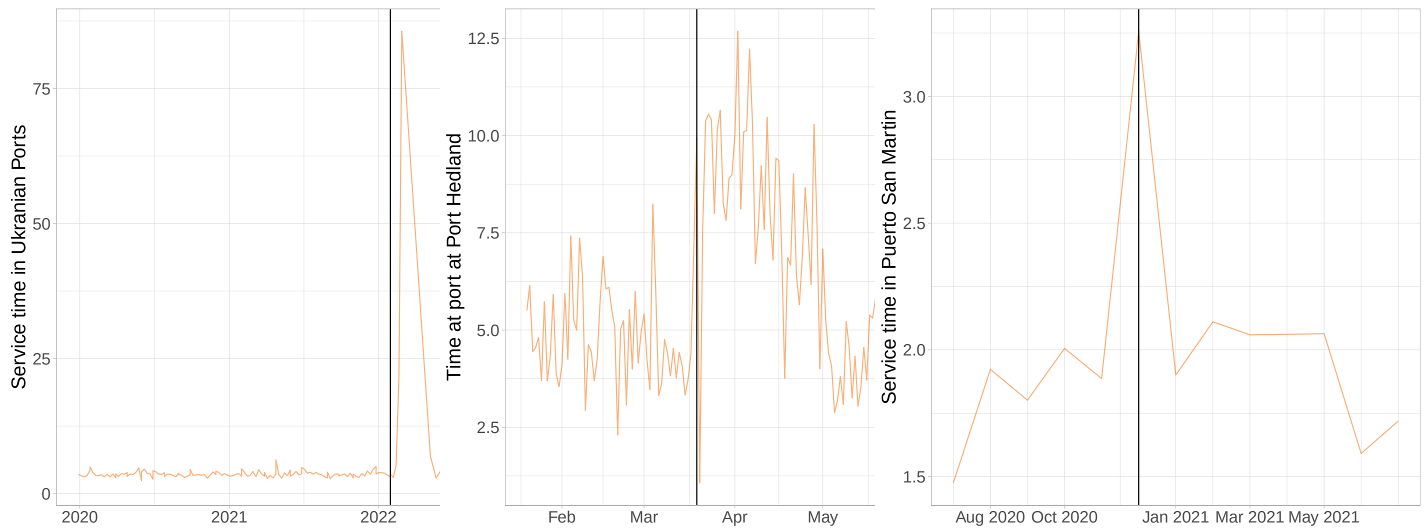

Figure 4: Examples of disruptions in port service time. The first panel plots the service time in Ukrainian ports before and after the beginning of the war. The second panel plots congestion in Port Hedland, Australia before and after the landfall of Cyclone Veronica in March 2023. The last panel plots the service time in Puerto San Martin, Argentina, before and after a strike that disrupted port operations in December 2020.

and disrupted iron ore exports. Finally, the third panel plots the increase in service time in the port of Puerto San Martin, Argentina, before and after a strike that disrupted port operations in December 2020.

Queueing theory provides a simple and intuitive measure of a port's "fragility" (Larson and Odoni, 2007), capturing how close it is to becoming overwhelmed. It relies on the three key determinants of time at port, i.e. service time, port capacity and demand. Intuitively, the ability of the port to avoid these explosive dynamics in wait time depends on how many ships it can service in every period, relative to the number of new ships arriving. In particular, suppose it takes T days to service each ship, the port can handle K ships at the same time, and N ships arrive every day. Then if the number of arrivals, N, is approaching the number of ships the port can service, K/T, the servers have increasing difficulty keeping up with new ship arrivals. In general, the ratio of ship arrivals to ships being serviced, given by

$$\rho \equiv \frac{N}{K/T},$$

is a measure of average port utilization: as $\rho \to 1$, port infrastructure gets overwhelmed and the queue explodes.

This statistic helps visualize how a combination of high demand and high service time (because of personnel and other types of restrictions) overwhelmed the international system of ports during the COVID-19 Pandemic. Figure 5 plots the distribution of the estimated ρ for the 50 largest US ports, both

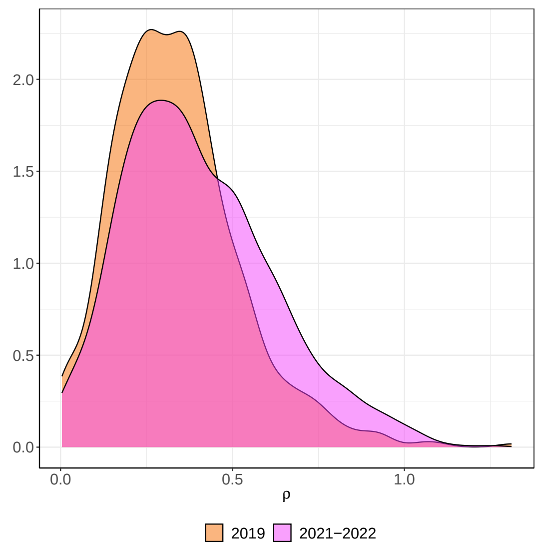

Figure 5: This figure plots a key measure of fragility proposed by queueing theory: $\rho \equiv \frac{N}{K/T}$ where T is the mean number of days it takes to service each ship, K ships is the number of ships that the port can simultaneously handle, and N is the mean number of ships that arrive every day. This statistic is plotted for the 50 largest US ports.

before (2019) and during the great supply chain disruption (2021-2022). This distribution has shifted to the right, suggesting ports are much more fragile during this period; in practice this resulted in high wait times and ship bottlenecks.

4 Trade Response

Of course none of this matters if what happens in the transportation sector does not affect macro outcomes, perhaps a dominant view until recently. However, a recent literature has shown that both ship and port bottlenecks have a significant impact on international trade, as well as commodity prices.

Several studies have recently estimated the trade elasticity with respect to freight rates. In the context of commodities, Brancaccio et al. (2020) estimate an elasticity equal to 1, using a tariff instrument that shifts ships' asymmetric profitability at different regions. In the context of manufacturing and container shipping, Wong (2022) estimates an elasticity of 3. Naturally, given the volatility of prices discussed above, the resulting change in trade can be substantial. This also explains policymakers' concerns about rising shipping costs which, as shown in Figure 1, more than doubled (and in the case of containers increased almost tenfold) following the COVID-19 Pandemic.

Similarly, there is great interest in assessing the impact of port congestion. In Brancaccio et al. (2024) we show that time at port has a substantial impact on trade passing through US ports. We do so using an instrument based on unexpected disruptions in port service times (such as crane breakdowns). We illustrate that ships react to changes in port congestion by changing the port they use; in fact, more than two thirds of trips do not use the most attractive port geographically (i.e. the one that is likely closest to their inland destination/origin) in order to avoid congestion. Additionally, we find that the elasticity of trade with respect to port congestion can be substantial.

Recent work has also focused on the impact of port congestion on inflation, including Benigno (2022), Michail et al. (2022), Alessandria et al. (2023), Blanchard and Bernanke (2023), Carrière-Swallow et al. (2023), Comin et al. (2023) and (2024), and Amiti et al. (2024). In Brancaccio et al. (2025) we show that port congestion for bulk carriers has a significant impact on commodity price inflation. Bai et al. (2024) show that port congestion for container shipping has a significant impact on the CPI.

This recent evidence suggests that transportation disruptions have a sizable impact on the entire economy, and implies that policy interventions in the sector (such as investment in infrastructure, labor relations, automation in ports) could have important welfare consequences.

5 Conclusion

In this paper we provide a simple and intuitive story for supply chain disruptions driven by the rigidities of the transportation sector. Macro shocks meet a steep supply curve, driven by equilibrium bottlenecks in ships (transportation agents) and ports (transportation infrastructure). This leads to highly volatile freight costs and time at port. As both trade and inflation respond, disruptions pass through to the entire economy.

References

Alessandria, G., S. Y. Khan, A. Khederlarian, C. Mix, and K. J. Ruhl (2023): "The aggregate effects of global and local supply chain disruptions: 2020–2022," *Journal of International Economics*, 146, 103788.

Amiti, M., O. Itskhoki, and D. E. Weinstein (2024): "What Drives US Import Price Inflation?" in *AEA Papers and Proceedings*, American Economic Association 2014 Broadway, Suite 305, Nashville, TN 37203, vol. 114, 106–111.

Bai, X., J. Fernández-Villaverde, Y. Li, and F. Zanetti (2024): "The causal effects of global supply chain disruptions on macroeconomic outcomes: evidence and theory," *NBER Working Paper*, 32098.

Benigno, G. (2022): "The GSCPI: A New Barometer of Global Supply Chain Pressures," .

Blanchard, O. J. and B. S. Bernanke (2023): "What caused the US pandemic-era inflation?" Tech. rep., National Bureau of Economic Research.

Brancaccio, G., M. Kalouptsidi, and T. Papageorgiou (2020): "Geography, Transportation, and Endogenous Trade Costs," *Econometrica*, 88, 657–691.

——— (2024): "Investment in Infrastructure and Trade: The Case of Ports," Tech. rep., National Bureau of Economic Research.

Brancaccio, G., M. Kalouptsidi, T. Papageorgiou, and Y. Zhou (2025): "Transportation Disruptions and Inflation," Tech. rep.

Carrière-Swallow, Y., P. Deb, D. Furceri, D. Jiménez, and J. D. Ostry (2023): "Shipping costs and inflation," *Journal of International Money and Finance*, 130, 102771.

Comin, D., R. C. Johnson, and C. Jones (2023): "Supply Chain Constraints and Inflation," *NBER Working Paper*.

——— (2024): "Import Constraints," *AEA Papers and Proceedings*, 114, 118–123.

Dunn, J. and F. Leibovici (2024): *Navigating the Waves of Global Shipping: Drivers and Aggregate Implications*, Federal Reserve Bank of St. Louis, Research Division.

Kalouptsidi, M. (2014): "Time to Build and Fluctuations in Bulk Shipping," *American Economic Review*, 104, 564–608.

Larson, R. C. and A. R. Odoni (2007): *Urban Operations Research*, Dynamic Ideas, 2nd ed.

Michail, N. A., K. D. Melas, and L. Cleanthous (2022): "The relationship between shipping freight rates and inflation in the Euro Area," *International Economics*, 172, 40–49.

Stopford, M. (2009): *Maritime Economics*, London and New York: Routledge, 3rd ed.

Wong, W. F. (2022): "The Round Trip Effect: Endogenous Transport Costs and International Trade," *American Economic Journal: Applied Economics*, 14, 127–166.