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Container shipping: A market equilibrium perspective on freight rates formation post-Covid-19

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Abstract

The unprecedented container shipping freight rate levels post-Covid-19 are studied in a stochastic dynamic partial equilibrium framework. The proposed container marked model is calibrated on annual aggregate data from the two recent decades. The observed freight rate levels in 2021 and 2022 match a switch of competitive equilibria from Bertrand to Cournot competition. Whereas increased costs and reduced productivity play a role in explaining freight rates, these factors alone appear not to be able to justify the high post-Covid-19 freight rate levels.

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Keywords

Container shipping alliances; Shipping freight rates; Oligopoly

JEL classification

R41; D43

1. Introduction

During the early phase of the Covid-19 pandemic, major disruptions to the global maritime logistic system were perceived as real risks. Shortage of crew due to tight regulations on the mobility of sailors (Heiland & Ulltveit-Moe, 2020), disruptions to railroad and barge services and reduced availability of skilled port labour and truck drivers (Gui et al., 2022), blanked sailings, i.e., container shipping schedule cancellations (Notteboom et al., 2021), disruptive effects on container trade network connectivity (Dirzka and Acciaro, 2022, Guerrero et al., 2022) and dislocation and regional shortage of empty containers (Toygar et al., 2022) jeopardized global trade and prosperity. At the start of the pandemic, the short run outlook appeared grim for the container shipping industry (Koyuncu et al., 2021).

The pandemic itself, and the governments' measures to contain the disease, did not cause a breakdown of the maritime logistic system. Hayakawa & Mukunoki (2021) point out that "the harmful effects of Covid-19 on international trade were accommodated after the first wave of the pandemic to some extent".

Aggregate global activity numbers for the container shipping industry for 2020 and 2022 are now available, and macro studies can supplement early studies that relied on micro observations, e.g., satellite data, ships' position and status information from container operators, and freight market data from ship brokers.

Fig. 1 shows the China Containerized Freight Index (CCFI) for 2002 to 2022. In contrast to concerns regarding the outlook for the industry at the outbreak of Covid-19, the container market enjoyed its most profitable years every during the pandemic.

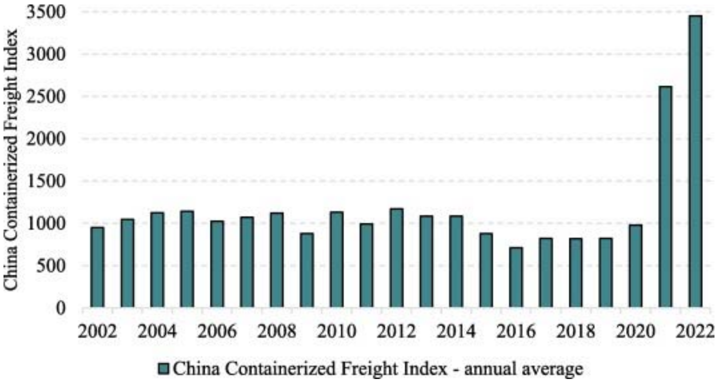

Fig. 1. The China Containerized Freight Index 2002–2022. Basis: Jan. 1, 1998, 1000 basis points. Source: Statista (Worldwide; MacroMicro; SSE).

In this study, we investigate the hypothesis that the disruption to container shipping, during and immediately after Covid-19, to some degree followed from operators' reactions to the crisis, creating a change in market equilibria from price to quantity competition, and not only followed from negative productivity shocks, due to the pandemic itself and governments' measures to contain the disease. We develop an aggregate oligopoly model of global container shipping and apply the framework for discussing ex-ante- and ex-post-Covid-19 market equilibria.

For recent discussions of the competitive structure of the container market see Notteboom et al., 2021, Merk and Teodoro, 2022, Ghorbani et al., 2022, and Monios & Wilmsmeier (2022). See also Sys (2009), who characterises the market structure of containerised liner shipping – dependent on trade lines – as loose to tight oligopoly. Our study of a potential temporary switch of competitive equilibrium appears to be novel to the container transport literature. However, switches of competitive structure have been studied for other transport sectors, e.g. the airline industry (Brander and Zhang, 1990, Brander and Zhang, 1993, Oum et al., 1993).

The paper is structured as follows. In section 2 we develop a stochastic partial equilibrium model for the container market, under price and quantity competition, and estimate the parameters of the model on aggregate market data. In section 3 we discuss, based on the model, the case for a switch of competitive equilibria post-Covid-19. Section 4 concludes.

2. A stochastic partial equilibrium model of the container freight market

In this section we develop a stochastic continuous time partial equilibrium model for the container freight market and apply the model to study the effect on freight rate dynamics from changes in market structure. Throughout Latin capital letters represent aggregate stochastic variables.

2.1. The structure of the theoretical model

Let instantaneous demand for container transport services at time *t* be given by

$$Q_t = Y_t X_t^{-\varepsilon} \tag{1}$$

where Q_t is aggregate demand, X_t is the container transport freight rate and Y_t is a stochastic demand scalar – all at time *t*. The parameter $-\varepsilon$ is a fixed price elasticity of demand. Let the aggregate demand scalar be given by a geometric Brownian motion satisfying the stochastic differential equation

$$dY_t = \mu Y_t dt + \sigma Y_t dB_t \tag{2}$$

where the constant μ is the expectation and the constant σ is the standard deviation of the relative change in the demand scalar and $dB_t \sim N(0, dt)$ is the increment of a standard Brownian motion.[1]

Let there be a limited number, *n*, of identical shipowners/operators that at time *t* provide total supply of a homogenous service, given by the sum of identical constant return to scale Cobb-Douglas production functions[2]

$$Q_t = nq_t = n\gamma {k_t}^{1-\beta} {l_t}^{\beta} \tag{3}$$

where q_t is the representative operator's output, k_t is the available capital/tonnage of the representative operator, l_t is a variable input factor, e.g., labour or fuel, $\beta \in (0,1)$ is the output elasticity parameter of the variable input factor and γ is a total productivity scalar parameter.

Let the variable input factor be available at a constant unit cost, w. Aggregate tonnage at time *t* is $K_t = n\,k_t$. Tonnage is only gradually accumulated and follows from investment decisions in response to the change in the aggregate demand scalar. Let the change in tonnage of a representative operator at time *t* be given by

$$dk_t = \kappa(ln(\lambda) + lnY_t - lnK_t)k_t dt \tag{4}$$

where κ, λ and n are constants.[3] The scalar λ aligns the ratio Y_t/K_t with the relative change in individual tonnage. The scalar has no implications for the analysis but is useful when calibrating the model.

From (4) it follows that the relative change in individual tonnage, k_t, is positive if the aggregate demand scalar, Y_t, is high versus the available aggregate tonnage, K_t, and vice versa. The change in tonnage is gradual and reflects time-to-build, technical and economic scrapping and the shipowner's willingness to invest. The relative change in individual tonnage may be negative, to reflect the case that depreciation and demolition exceed new investments. The speed of capital accumulation depends on the reversion parameter κ.[4] This specification appears to be a convenient alternative to the tonnage accumulation switching model of Tvedt (2003).

We consider two instantaneous equilibria – an oligopoly under price competition, i.e., a Bertrand equilibrium, and an oligopoly under quantity competition, i.e., a Nash-Cournot equilibrium.

The representative operator's instantaneous profit, disregarding cost of capital, under Bertrand competition, is given by $\pi_t = X_t q_t(k_t, l_t) - wl_t$. The representative operator's profit maximation gives the aggregate supply function

$$Q_t = (\gamma)^{\frac{1}{1-\beta}} \beta^{\frac{\beta}{1-\beta}} w^{\frac{-\beta}{1-\beta}} nk_t {X_t}^{\frac{\beta}{1-\beta}} \tag{5}$$

Price equal marginal cost gives the market equilibrium freight rate at time *t*

$$X_t = \left(\frac{\beta}{w}\right)^{\frac{-\varphi\beta}{1-\beta}} \gamma^{\frac{-\varphi}{1-\beta}} {Y_t}^{\varphi} n^{-\varphi} {k_t}^{-\varphi} \tag{6}$$

where $\varphi = \frac{(1-\beta)}{\varepsilon+\beta-\varepsilon\beta}$.[5] From (2), (4) and (6) it follows from Ito's lemma that the dynamics of the freight rate under Bertrand competition is given by

$$dX_t = \kappa\left(\alpha^B - lnX_t\right)Xdt + \widehat{\sigma}X_t dB_t \tag{7}$$

where $\alpha^B = \varphi\left(\frac{1}{\kappa}\left(\mu + \frac{1}{2}(\varphi-1)\sigma^2\right) - ln\lambda + \left(\frac{\beta}{1-\beta}\right)\left(lnw - ln\beta - \frac{ln\gamma}{\beta}\right)\right)$ and $\widehat{\sigma} = \varphi\sigma$, i.e., the freight rate follows a geometric mean reversion process. See (J. Tvedt, Valuation of VLCCs under income uncertainty 1997) for properties and the derivation of moments. The parameter α^B represents the long run mean level of the freight rate – in logarithmic form. The mean level increases in the value of the parameter μ, and decreases in the value of the parameters β, ε and κ. For inelastic demand the mean level increases, and for elastic demand the mean level decreases, in the value of the volatility parameter σ.

A high growth rate of the aggregate demand scalar, μ, relative to the reversion parameter, κ, implies a high long run average freight rate, i.e., the case that shipowners only slowly react to favourable demand conditions by ordering new tonnage. A high cost of the variable production factor, w, implies a high long run average freight rate.[6] Inelastic demand and inelastic output elasticity increase the standard deviation of the relative change of the freight rate, $\widehat{\sigma}$.

The representative operator's instantaneous profit, disregarding cost of capital, under Cournot competition, is given by $\pi_t = X_t(k_t, l_t)q_t(k_t, l_t) - wl_t$, where $X_t = {Y_t}^{-\frac{1}{\varepsilon}}\left((n-1)\overline{q} + \gamma {k_t}^{1-\beta}{l_t}^{\beta}\right)^{-\frac{1}{\varepsilon}}$ and $\overline{q}$ is the (assumed) given output of a representative competitor. The Nash-Cournot equilibrium freight rate at time *t* is given by optimal individual output via adjustment of the variable production factor, l_t, given the output of the $n-1$ competitors,

$$X_t^C = \left(1 - \frac{1}{n\varepsilon}\right)^{\frac{-\varphi\beta}{1-\beta}} \left(\frac{\beta}{w}\right)^{\frac{-\varphi\beta}{1-\beta}} \gamma^{\frac{-\varphi}{1-\beta}} {Y_t}^{\varphi} n^{-\varphi} {k_t}^{-\varphi} \tag{8}$$

for $0 \leq \frac{1}{n\varepsilon} < 1$.[7] It follows that the dynamics of the freight rate under Cournot competition is given by

$$dX_t^C = \kappa\left(\alpha^C - lnX_t^C\right)X_t^C dt + \widehat{\sigma}X_t^C dB_t \tag{9}$$

where $\alpha^C = \varphi\left(\frac{1}{\kappa}\left(\mu + \frac{1}{2}(\varphi - 1)\sigma^2\right) - ln\lambda + \left(\frac{\beta}{1-\beta}\right)\left(lnw - ln\left(1 - \frac{1}{n\varepsilon}\right) - ln\beta - \frac{ln\gamma}{\beta}\right)\right)$. Given the requirement that $0 \leq \frac{1}{n\varepsilon} < 1$ then $-\infty < ln\left(1 - \frac{1}{n\varepsilon}\right) \leq 0$, which implies that $\alpha^C \geq \alpha^B$, i.e., the long run average[8] of the freight rate process in the case of a Nash-Cournot equilibrium is equal to or higher than in the case of a Bertrand equilibrium.

The standard deviations of the relative change in the freight rate, $\widehat{\sigma}$, are equal in the Cournot and Bertrand competition cases. The freight rate processes are geometric, which implies low absolute volatility if freight rates are low and high absolute volatility if freight rates are high. Therefore, freight rates in a Cournot market will appear more volatile than in a Bertrand market, given the higher average freight rate level in the Cournot setting. Relatively, freight rate volatility is the same under both types of competition. Note that this result is model specific. For alternative model specifications competitive equilibria are likely to affect relative freight rate volatility.

The expected value and the variance of the log of the freight rate, in the Bertrand equilibrium case, are respectively (Tvedt, 1997):

$$E[\ln X_\tau | \mathscr{F}_t] = \left(\alpha^B - \frac{\widehat{\sigma}^2}{2\kappa}\right)\left(1 - e^{-\kappa(\tau - t)}\right) + e^{-\kappa(\tau - t)} \ln X_t \tag{10}$$

$$Var[\ln X_\tau | \mathscr{F}_t] = \frac{\widehat{\sigma}^2}{2\kappa}\left(1 - e^{-2\kappa(\tau - t)}\right) \tag{11}$$

where $\mathscr{F}_t$ is a filtration of available information up to time *t*.

The model is general and may find applications beyond container shipping. Closed form solutions to basic freight rate derivatives based on (13) are available (Tvedt, 2019), which suggest potential for extending the model to real options and other asset valuation applications.

2.2. Calibrating the model

The parameters of the continuous time Bertrand model may be derived via estimation of discrete versions of the static freight rate relation (6) and the dynamic freight rate relation (13). Parameter values may be derived from the estimated coefficients of the following equations, if data for the underlying variables are available,

$$ln\, X_t = \dot{\beta}_0 + \dot{\beta}_1 lnw_t + \dot{\beta}_2\left(lnY_t - ln(nk_t)\right) + \dot{\varepsilon}_t \tag{12}$$

$$ln\, X_t = \breve{\beta}_3 + \breve{\beta}_4 lnX_{t-1} + \breve{\varepsilon}_t \tag{13}$$

where $\dot{\beta}_0 = \frac{-1}{\varepsilon - \varepsilon\beta + \beta}(\ln\gamma + \beta ln\beta)$, $\dot{\beta}_1 = \frac{\beta}{\varepsilon - \varepsilon\beta + \beta}$, $\dot{\beta}_2 = \frac{(1-\beta)}{\varepsilon - \varepsilon\beta + \beta} = \varphi$, $\breve{\beta}_3 = \left(\alpha^B - \frac{\widehat{\sigma}^2}{2\kappa}\right)(1 - e^{-\kappa})$, $\breve{\beta}_4 = e^{-\kappa}$ and $\breve{\varepsilon}_t \sim N\left(0, S^2\right)$, such that via (11) $\widehat{\sigma} = S\sqrt{\frac{2ln\breve{\beta}_4}{\left(\breve{\beta}_4{}^2 - 1\right)}}$.

It may not be possible to observe directly, or find a good proxy for, the demand scalar Y_t. By solving for Y_t in the demand relation (1), and substituting Y_t in (12), we get a static relation for the freight rate relative to the price of the variable input factor, which depends on the production of transport services and aggregate tonnage, i.e.,

$$ln\, X_t - lnw_t = \overline{\beta}_0 + \breve{\beta}_2\left(lnQ_t - ln(nk_t)\right) + \varepsilon_t \tag{14}$$

where $\overline{\beta}_0 = -\frac{\ln\gamma}{\beta} - ln\beta$ and $\breve{\beta}_2 = \frac{1-\beta}{\beta}$. That is, from the estimation of equation (14), the parameters of the production function (3) can be derived.

As a proxy for a global container freight rate, X_t, we use the annual average of the China Export Containerized Freight Index (CCFI). For production, Q_t, we use the annual observations of global container port throughput, in terms of twenty-foot equivalent units – available from UNCTAD from 2000 to 2021.[9] For total fleet capacity, $n_t k_t$, we use UNCTAD's aggregate container ship fleet data.

As a proxy for the price of the variable input factor, w_t, we use the annual average of the Brent blend crude oil price, p_t. Fuel cost is the major part of the variable costs of a container operation. Regional bunkers prices are strongly linked to the crude oil price. However, ignoring other variable costs, i.e., primarily harbour charges and cost of crew, and using the crude oil price as proxy for the bunkers price, may give excessive volatility in w_t. In order to dampen excess volatility, we let w_t be an exponential function of the Brent blend crude oil price and move the term $w_t = \varrho(Brent_t)^\zeta$ to the right of equation (14), where ϱ and ζ are constants.

From the variable cost approximation, the equilibrium aggregate supply (8) and freight rate (9) are, respectively

$$Q_t = \left(\frac{\beta}{\Gamma}\right)^{\frac{\beta}{1-\beta}} (p)^{\frac{-\zeta\beta}{1-\beta}} nk_t X_t^{\frac{\beta}{1-\beta}} \tag{15}$$

and

$$X_t = \left(\frac{\beta}{\Gamma}\right)^{\frac{-\varphi\beta}{1-\beta}} (p)^{\frac{\zeta\varphi\beta}{1-\beta}} {Y_t}^{\varphi} n^{-\varphi} {k_t}^{-\varphi} \tag{16}$$

where $\Gamma = \varrho\gamma^{\frac{-1}{\beta}}$. From the static freight rate relation (15), it follows that

$$ln\,X_t = \check{\beta}_0 + \check{\beta}_1 ln(p_t) + \check{\beta}_2 (lnQ_t - ln(nk_t)) + \varepsilon_t \tag{17}$$

where $\check{\beta}_0 = ln\varrho - \frac{ln\gamma}{\beta} - ln\beta$, $\check{\beta}_1 = \zeta$ and as above $\check{\beta}_2 = \frac{1-\beta}{\beta}$. For a given value of the variable cost scalar ϱ – the choice of ϱ does not affect the market equilibrium – the productivity scalar of relation (3), γ, can be derived.

To estimate the demand elasticity, we apply a “black hole” observation approach, i.e., to infer approximate size of the unobservable object by the object’s gravity on other objects. Observe that capital accumulation is given by the gravity towards the unobserved demand scalar Y_t. That is, from relation (4) the log of the demand scalar can be expressed in terms of the log of aggregated capital, lagged log of aggregated capital, and the gravity given by the mean reversion parameter κ, i.e.,

$$ln\,Y_t = \frac{lnk_t}{\kappa} - \frac{lnk_{t-1}}{\kappa} + ln(nk_t) - ln\lambda \tag{18}$$

From (12), (18) and the variable cost proxy, i.e., the Brent blend crude oil price, it follows that the log of the freight rate is given by

$$ln\,X_t = \overline{\overline{\beta}}_0 + \overline{\overline{\beta}}_1 ln(p) + \overline{\overline{\beta}}_2 (ln(nk_t) - ln(nk_{t-1})) + \overline{\overline{\varepsilon}}_t \tag{19}$$

where $\overline{\overline{\beta}}_0 = -\varphi\left(\frac{1}{1-\beta}\left(\frac{ln\gamma}{\beta} + ln\beta - ln\varrho\right) + ln\lambda\right)$, $\overline{\overline{\beta}}_1 = \zeta\frac{\beta}{1-\beta}\varphi$ and $\overline{\overline{\beta}}_2 = \frac{\varphi}{\kappa} = \frac{(1-\beta)}{\kappa(\varepsilon-\varepsilon\beta+\beta)}$. The demand elasticity, $-\varepsilon$, can be derived from $\overline{\overline{\beta}}_2$, for given β and κ.

Aggregate supply and freight rate in a Cournot equilibrium, given the variable cost proxy, are respectively

$$Q_t^C = \left(1 - \frac{1}{n\varepsilon}\right)^{\frac{\beta}{1-\beta}} \left(\frac{\beta}{\Gamma}\right)^{\frac{\beta}{1-\beta}} (p)^{\frac{-\zeta\beta}{1-\beta}} nk_t {X_t}^{\frac{\beta}{1-\beta}} \tag{20}$$

and

$$X_t^C = \left(1 - \frac{1}{n\varepsilon}\right)^{\frac{-\varphi\beta}{1-\beta}} \left(\frac{\beta}{\Gamma}\right)^{\frac{-\varphi\beta}{1-\beta}} (p)^{\frac{\zeta\varphi\beta}{1-\beta}} {Y_t}^{\varphi} {n_t}^{-\varphi} {k_t}^{-\varphi} \tag{21}$$

Note that the Bertrand and Nash-Cournot equilibria’s volumes and prices, i.e., relations (15), (16), (20) and (21), are defined by the same set of parameters. The only additional information required to define the Nash-Cournot equilibrium is the number of representative market agents, *n*.

Table 1 shows the estimation of equations (13), (17) and (19) on the data described above. The results are derived by ordinary least squares estimation, with heteroskedasticity and autocorrelation consistent estimation of standard errors (OLS-HAC).

Table 1. Estimated parameters of the Bertrand equilibrium container freight rate model (Eqs. (13), (17) and (19)), annual observations 2002–2019.

Model	β_0	β_1	β_2	$\check{\beta}_3$	$\check{\beta}_4$	**DW**	$\overline{R}^2$
Dynamic relation (13)	–	–	–	2.86(1.16**)	0.585(0.166***)	–	0.27
Static relation (17)	−3.54(2.34)	0.150(0.053**)	1.21(0.283***)	–	–	0.95	0.57
Lagged relation (19)	6.25(0.33***)	0.123(0.073)	1.73(0.75**)	–	–	1.52	0.16

HAC standard errors in parentheses, bandwidths are equal to one in all cases (Bartlett kernel), sign.10%*, 5%**, 1%***. Standard error of the dynamic relation regression, $S = 0.130$.

Table 2 shows parameter values derived from the estimated coefficients in Table 1. The relations between regression coefficients and parameter are as specified by the model above – under the assumption that the container market for 2002–2019 cleared as Bertrand equilibria.

Table 2. Estimated parameter values for the Bertrand equilibrium container freight rate model, annual observations 2002–2019.

Parameter	*Description*	*Value*
β	Output elasticity	0.452
γ	Production scalar, for $\varrho = 1$	7.10
ε	Price elasticity of demand	0.0595
ζ	Crude oil price elasticity of variable costs (proxy)	0.132
κ	Investment response parameter	0.536
λ	Scalar relating the demand scalar to tonnage	0.000211
μ	Geometric trend of demand	0.0683
σ	St. dev. of relative change in demand	0.147

3. The case for a switch of equilibria post-Covid-19

After a decline in global container port throughput in 2020, activity increased in 2021 to slightly above pre-Covid-19 levels. In absolute terms, and relative to the growth in global GDP, the increase in port throughput during the Covid-19 recovery has been moderate. The annual average freight rate increased in 2020, despite a slight decrease in throughput. In 2021 and 2022 freight rates shifted upwards to unprecedented levels. A key question is whether the high freight rates, and the container operators' record returns on capital post-Covid-19, represent short-term technical supply-side disruptions or structural breaks in the way the container shipping market works.

At the start of the pandemic, restrictions that limited the availability of sailors and disruptions in ports, appeared to have shifted the global container market supply curve inwards. Widespread occurrences of blanked sailings, via public announcements, and high utilisation rates of large deep-sea container vessels, point towards a switch of market equilibria. The switch may have been triggered by grim prospects for the industry at the start of the pandemic, e.g., Cariou & Guillotreau (2022) find that 'coordinated' reduction in container shipping capacity is more likely if excess capacity is high, which incentivise cooperation. A temporary inwards shift in the supply curve, and a recognition by market agents that the business model of the past was unsustainable going forward, may have triggered a switch of market equilibria from price to quantity competition. After the lifting of the lockdown, and the recovery in global demand, the new quantity-based equilibrium appears to have persevered.

3.1. Freight rate dynamics and basic demand and supply factors

As a starting point, we disregard a potential switch of competitive equilibria. We assume that the annual relative change in the container freight rate index can fully be explained by a set of basic demand and supply factors – represented by a proxy for the global business cycle, a proxy for capacity and a proxy for variable costs.

In equation (22), the relative change in the container transport freight rate index, $ln\,\frac{X_t}{X_{t-1}}$, is explained by the Kilian index, the aggregate size of the container fleet and fuel costs.

$$ln\,\frac{X_t}{X_{t-1}} = \widetilde{\beta}_0 + \widehat{\beta}_1 Y_t^{KI} + \widetilde{\beta}_2 ln\frac{K_t^{Ton}}{K_{t-1}^{Ton}} + \widetilde{\beta}_3 ln\frac{w_t^{Brent}}{w_{t-1}^{Brent}} + \sum \widetilde{\beta}_{Year} D_t + \widetilde{\varepsilon}_t \quad (22)$$

Annual observations of the container transport freight rate, X_t, is given by the yearly average of the China Containerized Freight Index, from 2002 to 2022.

The Kilian index, Y_t^{KI}, represents an early available indicator of demand conditions that mirrors global GNP, manufacturing activity – especially in Asia, and the general business cycle of the maritime industry (Kilian, 2009, Kilian, 2019, Kilian and Zhou, 2018). We use annual averages of the monthly Kilian index, from the Federal Reserve Bank of Dallas.

Annual capacity in the container shipping industry, K_t^{Ton}, is represented, as above, by the aggregate container fleet, measured in thousand deadweight tons, from UNCTAD.

Fuel, the main variable cost of a container vessel, w_t, is represented, as above, by the annual average of the Brent blend crude oil price.

The basic model (22) explains a significant part of the relative change in the freight rate index for 2002–2022. (Table 3). A strong business cycle, represented by a high Kilian index, is related to a high freight rate. An expansion of available tonnage is related to lower freight rates. A change in the oil price has no significant effect on freight rates.[10]

Table 3. Relative change in the China Containerized Freight Index, the Kilian index (1), relative change in aggregate tonnage (2) and relative change in the Brent blend crude oil price (3), annual observations 2002–2022.

Model	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\beta}_3$	$\widetilde{D}_{2009}$	$\widetilde{D}_{2021}$	**DW**	$\overline{R}^2$
Basic model (22)	0.45(0.18**)	0.0027(0.0011**)	−6.44(2.38**)	0.13(0.09)	–	–	1.72	0.55
Dummies 2009& 2021	0.28(0.06***)	0.0020(0.0005***)	−3.96(0.95***)	–	−0.15(0.03***)	0.70(0.06***)	2.25	0.84

HAC standard errors in parentheses, bandwidths 2 and 2, respectively (Bartlett kernel), sign.10%*, 5%**, 1%***. Akaike information criterion (AIC) −9.1 and −28.9, respectively.

As an alternative to the basic model, we exclude the oil price and introduce dummies for the years following immediately after a US recession, i.e. we include dummies for the years 2009 and 2021. 2009 is the year that followed the start of the US recession that was triggered by the financial crisis. 2009 is also the first full year after the repeal of the liner conference exemption from EU competition law.[11] 2021 is the year that followed immediately after the short US recession that was triggered by the Covid-19 pandemic.[12]

Both dummies are significant at 1%. However, whereas the financial crisis recession dummy has a negative impact on freight rates, the pandemic recession dummy has a positive impact on freight rates. The dummies indicate the existence of explanatory factors that are not included in the basic model.[13] The negative dummy coefficient for 2009 coincides with the effectuation of the change in EU competitive law in 2008. However, it probably mainly reflects market responses to near future expected increases in supply following a high number of new container ships ordered in 2008 (Asariotis et al., 2009).

Near future over-supply did not appear to be a general concern among market agents late 2020 and in 2021, as the container ship order book at that time started to fill. The 2021 dummy coefficient, of 0.70, suggests a doubling of the freight rate index,[14] if the dummy value changes from zero to one.

3.2. Switch of competitive equilibria vs productivity shocks

The grey dashed line in Fig. 2 shows a random path of the theoretical price process under Bertrand competition, i.e. generated by equation (16), for a period of 30years. The path is generated by random white noise. The parameters are as specified in Table 2. The solid line shows the Nash-Cournot freight rate for the years 20 to 30, for the same white noise as the dashed line. The number of market agents, n, in the Cournot case is 25. The blue dotted lines show the future conditional expected freight rates – at time zero for the Bertrand random path and at time 20 for the Nash-Cournot random path. In this example, the freight rate at time 20 is slightly below the long-run mean level, which implies that in the Nash-Cournot case the conditional expected freight rate path is upward sloping. If the freight rate at time 20 had been above the long run mean the conditional expected freight rate path would have been downward sloping. The red dotted lines show the freight rates' confidence intervals under Bertrand and Nash-Cournot competition.[15]

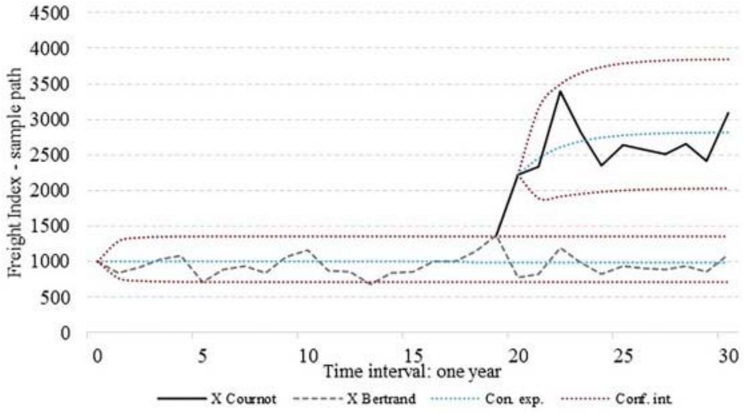

Fig. 2. A sample path of a model generated freight rate index in the case of Bertrand and Nash-Cournot competition – for identical white noise and parameter values.

Fig. 2 illustrates the upward shift in the freight rate level and the higher absolute freight rate volatility that follows from a change from price to quantity competition. Note that the freight rate's confidence interval after the switch of competitive equilibria, in period 20, is above the freight rate's confidence interval in the Bertrand case.

An upward shift in freight rate levels, without an increase in demand, may also follow from an increase in variable costs or from a negative productivity shock. It is reasonable to believe that reduced mobility of sailors, infection control measures and limited availability of port workers increased labour cost and reduced labour productivity. The fuel cost picture, however, has been mixed. The Brent blend crude oil price fell from an annual average of USD 64 per barrel in 2019 to USD 42 per barrel in 2020, while the oil price recovered to USD 71 per barrel in 2021. According to the model, the changes in variable costs, mainly driven by fuel price volatility, are hardly large enough to explain the jump in container shipping freight rates post-Covid-19.

During the pandemic, port handling of containers appears to have been hampered, i.e., port and total industry productivity were negatively affected. Notteboom et al. (2021) report that blanked sailings implied significantly fewer vessel calls between April and June 2020 on main trades out of Asia. Container throughout was less impacted by the pandemic than the number of port calls.[16] Blanked sailings resulted in increased call sizes, which caused operational hurdles like peaks in ship-to-ship operations and yard activities and gate congestions. A high number of blanked sailings in the early phase of the pandemic created disruptions in the container trade network connectivity. Guerrero et al. (2022) find that most ports lost connectivity to some degree, especially ports that had hub or bridge functions.

To some extent the negative effect on productivity and connectivity appears to follow from container operators' strategic choices in the early phase of the pandemic. In contrast to the 2008/2009 downturn, from the early phase of the pandemic container operators resorted to capacity management (Notteboom et al., 2021). Bai et al. (2022) find that the initial lockdown in China induced container operators to take up capacity adjustment strategies to cope with the decline in demand. The response created propagation effects from Chinese ports through the global container shipping network. The capacity adjustments during the early phase of the lockdown appear to have contributed to reducing the productivity of the logistic system, and pushed freight rates upwards, despite weak demand conditions.

Fig. 3 shows static demand and supply functions for the global container shipping market. The functions are given by the above estimated parameters. The demand function '2019' and the Bertrand '2019' supply function are calibrated on 2019 observations. The demand '2019' function and the Bertrand '2019' supply function cross at a freight rate index of 858 and a volume of 837 million TEU.

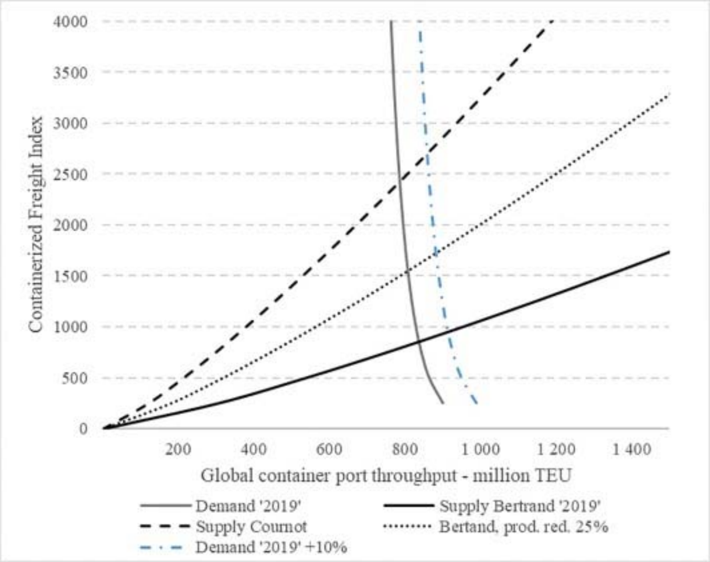

Fig. 3. Market equilibria in the global container market under price or quantity competition – calibrated on 2019 observations.

The dashed line is the Cournot supply function for $n = 25$. The demand '2019' function and the Cournot supply function cross at a freight rate index of 2433 and a volume of 786 million TEU. That is, the freight rate index increases by 183% due to the change from price to quantity competition.

The dotted line is the Bertrand supply function in the case that total productivity is reduced by 25%, i.e. the total factor productivity scalar, γ, is reduced by 25%. The demand and supply functions now cross at a freight rate index of 1555 and a volume of 808 million TEU. That is, the freight rate index increases 81% due to a 25% reduction in total factor productivity.

Productivity must drop almost 40% for the freight rate index under Bertrand competition to match the freight rate index under Cournot competition. In other words, a 40% reduction in total factor productivity creates a shift inward in the supply curve, that matches the shift inward in the supply curve, from a switch in competitive equilibrium from Bertrand to Nash-Cournot. That is, a 40% negative total factor productivity shock establishes a Bertrand equilibrium, which mirrors the Nash-Cournot equilibrium in the case of no productivity shock and $n = 25$. This shows that a major total factor productivity shock can create a market state, under price competition, that resembles a quantity-based equilibrium under normalized productivity. This may be key for understanding the recent dynamics of the container shipping industry.

In 2021 the annual average of the China Containerized Freight Index was 2615 and the container port throughput was 849 million TEU. An outward shift in demand, given by an 8.5% increase in the demand scalar Y_t, is enough to push the Cournot '2019' freight rate index up to the observed freight rate index of 2021 (Blue dash-dotted line).

3.3. Framework limitations

The model is simple, aggregated and with limitations. The shift in freight rate levels, due to a switch from price to quantity competition, is sensitive to the choice of the number of market operators. Only a moderate increase in the number of operators reduces the average freight rate under Cournot competition significantly. As $n \to \infty$ the Cournot sample path of Fig. 2 approaches the Bertrand sample path.

In the model all operators are identical. The real world is more complex. The inhomogeneous group of the ten largest vessel operators control 91.5% of total fleet capacity (Notteboom et al., 2021). The industry is dominated by three alliances, i.e., 2M, The Alliance and Ocean Alliance.

During the recent decade mergers and the growth of the largest terminal operators have consolidated the container handling sector. From 2001 to 2018 the top ten port operators increased their share of container port throughput from 41% to 70% (Notteboom et al., 2021).

Considering the current concentration on the supply side, both of container vessel and cargo handling operators, it may be argued that 25 is a high number for n.[17] However, a too low number may exaggerate the freight rate effect from a change in competitive equilibrium. The choice of n is to some extent a question of calibration of the model correctly.[18]

In the model the short- and long run elasticities of demand are identical – equal to $-\varepsilon$. This is a simplification with implications for the long-run relevance of the model. In the long run, excessive freight rate levels may affect manufacturers' location choices, which may reduce demand for container transport. Demand may become more elastic over time if freight rate levels are persistently high.

One may argue that the calibration of the model is enhanced somewhat by applying a higher demand elasticity for the pandemic period. An increase in the static demand elasticity parameter from $\varepsilon = 0.0595$ to $\varepsilon = 0.0892$, i.e. an increase of 50%, implies that the parameter α^C, i.e., the log of the long run mean level of the freight rate, drops from 7.96 to 7.23. For $\varepsilon = 0.0892$ the number of competitors, n, must be reduced to 14.85 for the long run mean to stay at $\alpha^C = 7.96$. That is, the number of competitors will then be more in line with the actual number of major operators in the market.

The model's Nash-Cournot solution is a static equilibrium. The model does not consider that new players may be induced to enter the market, i.e., n will increase over time, if freight rate levels are persistently high.

The threat of new entries, and an elastic long-run price elasticity, will affect real-world market equilibria. Therefore, a Nash-Cournot equilibrium may not be stable long run. A quantity competitive equilibrium is probably dependent of some form of collusion – tacit or outright – in order to be stable over time.

Late 2022, container freight rates dropped significantly – the China Containerized Freight Index fell from a peak of 5.046 in December 2021 to 1.107 in December 2022 (monthly averages). The December 2022 index was only marginally above the pre-pandemic levels. A large orderbook, due to a pickup in new orders during the freight rate boom, meant that capacity restrictions were likely to be relaxed going forward. Anticipation of relaxed capacity restrictions in the future may have triggered a switch in competitive equilibrium, from quantity competition back to price competition, later 2022.

4. Conclusion

The paper presents a framework for discussing the hypothesis that a general acceptance of an immediate existential treat to the industry's business model, combined with port capacity restrictions in the early phase of the pandemic, triggered a switch of market equilibria from price to quantity competition. Supply side shocks (except for port efficiency shocks during the first weeks of the pandemic), like changes in tonnage, fleet utilisation and variable costs, probably affected the market during the pandemic, but these factors do not appear substantial enough to explain the large upward shift in freight rates. That is, a switch of competitive equilibria appears to be a possible explanation for the recent years' market volatility – in line with our hypothesis. Other explanations, like collusion, is outside the paper's analytical framework.

4.1. Findings

Our model shows that the unprecedented increase in container freight rates post-Covid-19, despite only a moderate increase in container port throughput, is consistent with a switch from price to quantity competition. If the price elasticity of demand is low, which empirically appears to be the case in global container shipping in the short run, a switch from a Bertrand type to a Nash-Cournot type equilibrium may cause a significant shift upwards in the freight rate level.

The model indicates that high freight rate levels in 2021 and 2022 are consistent with an initial negative supply side shock, caused by reduced productivity and to some degree higher costs, followed by a switch from price to quantity competition. Temporary negative supply side shocks, and a negative outlook for the industry during the first months of the pandemic, may have triggered a change in the competitive structure of international container shipping. In the early phase of the pandemic the shock to the industry's productivity moved the market to a new state, which in our model's context to some degree resembles a Nash-Cournot equilibrium under normal total factor productivity conditions. This new state appears to have persevered when the negative productivity shocks evaporated. The stability of the new equilibrium is questionable and a return to price competition is likely. The decline in container freight rates late 2022 – almost back to pre-pandemic levels – is consistent with a reversion to Bertrand competition, which follows from relaxed future quantity restrictions, due to an increase in the newbuilding orderbook and the risk of future entry of new players – attracted by excess container market profitability.

4.2. Policy implications

A switch from price to quantity competition creates a loss of aggregate consumer surplus, which outpaces the increase in container shipping profits. Any policy that weakens the stability of a Nash-Cournot equilibrium (or a tacit or outright collusion) and facilitates a return to price competition, reduces the cost of transport and enhances global welfare.

In the model the switch from a Bertrand to a Nash-Cournot equilibrium, based on the 2019 calibration, increases the return on total capital by 214%. The economic efficiency loss, due to the switch of competitive equilibrium, is in the model 4.6% of the increase in the return to capital. The loss may appear marginal considering the massive increase in freight rates – but follows from the low price elasticity of demand. That is, the main effect of a change in competitive equilibrium is a large transfer of wealth from consumers of transport services to the container shipping companies. The effect on transport services provided, i.e. the port throughput, is limited.

In the long run, the price elasticity is probably higher than the estimated short run elasticity applied in the calculations. Manufacturers' location choices and transport patterns may be adversely affected by high freight rates in the long run. Consequently, economic efficiency losses from enduring quantity competition may be higher than suggested by this study.

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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1 Empirically, global GDP may be applied as a proxy for the demand scalar. If so, a geometric Brownian motion assumption is in line with a unit root in the log of GDP. See the seminal paper of Nelson and Plosser (1982) and the related literature. The alternative, a trend-stationary demand scalar, would typically add to the mean reversion tendency of freight rates.

2 A richer specification of the supply function could include the case of lay-up, i.e., high supply elasticity for low freight rates, and the case of utilization close to a maximum, i.e. low supply elasticity for high freight rates. Empirically, a richer specification is especially relevant if the period studied is characterized by, on the one hand, significant changes in the degree of lay-up, or, on the other hand, carriers changing speed to adjust supply. During the pandemic neither seem to have affected the market to a large degree.

3 The number of supplies, n, could alternatively be dynamic – reflecting entry and exit choices of shipowners. The effect of this is discussed in more detail below.

4 This specification implies that investments increase in good times and vice versa. In the model, the speed of reversion, κ, is exogenous – reflecting the market's investment propensity dependent of market conditions. Alternatively, the speed of reversion could be determined from the solution of a stochastic optimal control problem, for a given specification of investment costs. However, this would add to the complexity of the model.

5 The equilibrium requires that all supplies are identical in terms of increasing marginal and average variable costs, which implies that an individual supplier will, as long as the price is above marginal cost, lower its offer to undercut its competitors' price to gain a larger market share. The capacity dynamics, relation (4), is a proxy for a Bertrand solution in which the long-run total average cost equal price and where there is no excess return on capital. However, it is outside the scope of this article to derive a long-run equilibrium in which capital returns are given by a financial market's pricing of time preference and risk. This may be an interesting area for further research.

6 Note that the parameter α^B depends on the fixed price of the variable production factor w. The real variable cost of operating a container vessel, i.e., mainly fuel and port charges, is volatile. However, freight rate volatility dominates cost volatility, which for our purposes may justify the model's constant variable cost assumption. However, large shifts in variable costs can affect market equilibria. A next step for future research may be to include supply uncertainty.

7 In the case that $\frac{1}{n\varepsilon} \geq 1$ the model is not defined, given that the specification then would imply that the individual optimal strategy is to set the freight rate infinitely high.

8 The term "long run average" is correct in this partial equilibrium setup but may be misleading in a long run general equilibrium model. A change in market structure may affect investment behavior. That is, in a general equilibrium model the parameters κ and n may be substituted by endogenous variables that reflects changes in investment behavior. Higher profitability in the Cournot case may increase the individual willingness to invest, whereas collusion in capacity may suggest deferred investments. The deferring effect on capital accumulation from collusion may be balanced by deterring investments to avoid new entrances.

9 Data are derived from The World Bank/UNCTAD. Preliminary data for 2021 is from Notteboom, Pallis and Rodrigue (2022) World Container Throughput, 1980–2021 | Port Economics, Management and Policy (porteconomicsmanagement.org↗). UNCTAD report data for 2010 – 2020 based on a revised method. The World Bank data is used here, due to the length of the data series. High frequency freight rate data is available, which may give additional insight into the timing of structural shifts. However, the study is restricted to annual data to match the frequencies of available throughput, fleet size and freight rate observations.

10 The specification of the model may partly explain the lack of significance of the oil price (high level of aggregation and annual time intervals). Notteboom and Vernimmen (2009) find that current bunker prices have a significant impact on the costs per TEU, operations are affected, but the cost increase is only partially compensated through surcharges. That is, the relationship between oil prices and freight rates is complex and works with delay. Wu and Huang (2018) empirically find that the oil price has a negative effect on the profitability of the three largest container shipping companies in Taiwan. Therefore, a positive correlation between oil price and freight rates are maintained in the equilibrium model, despite the lack of significance in table 3.

[11] Su and Wang (2016) find the North America – Europe trade routes to be competitive after the repeal of the exemption from EU competitive law, whereas the Far East – Europe trades remain partly non-competitive.

[12] Recessions are as defined by the National Bureau of Economic Research (NBER). NBER recessions peaks and troughs: 2001–03-01:2001–11-01, 2007–12-01:2009–06-01, 2020–02-01:2020–04-01.

[13] Akaike information criterion (AIC) for the basic model, without Brent blend as an explanatory factor, is –10.5. AICc (AIC adjusted for small samples) for the basic model is –9.8. AICc for the model with dummies is –26.2.

[14] .$exp(0.70) \approx 2.01$

[15] The model assumes that the log of the freight rate is normally distributed. Hence, the confidence intervals are given by $exp\left(E[\ln X_\tau|\mathscr{F}_t] \pm 2\sqrt{var[\ln X_\tau|\mathscr{F}_t]}\right)$ and the conditional expected value of the log-normally distributed freight rate is given by $E[X_\tau|\mathscr{F}_t] = exp\left(E[\ln X_\tau|\mathscr{F}_t] + \frac{1}{2} var[\ln X_\tau|\mathscr{F}_t]\right)$, for $t = 0, \tau = 0, \cdots, 30$ and Bertrand case parameters, and for $t = 20, \tau = 20, \cdots, 30$ and Cournot case parameters.

[16] The literature offers contradicting evidences, and the challenges of the industry appear to have changed throughout the pandemic, e.g., Zhu et al. (2020) find that Covid-19 did “not significantly affect the number of ships arriving at China’s ports” in the early phase of the pandemic, but the average berthing time was reduced. That is, the main challenge early 2020 was lack of demand, not port productivity or blanked sailings.

[17] From a model technical viewpoint, observe that the restriction $0 \leq \frac{1}{n\varepsilon} < 1$, and the estimated value ε in table 2, imply that the lowest possible positive natural number of n is 17.

[18] The long run average of the log of the freight rate under Cournot competition, α^C, is sensitive to the choice of n. For $n = 25$ $\alpha^C \approx 7.96$. For $n = 50$ $\alpha^C \approx 7.30$. For $n = 17$ $\alpha^C \approx 11.16$. For $n \to \infty$, $\alpha^C \to \alpha^B \approx 6.92$.
