Scale diseconomies and efficiencies of liner shipping

In the context of liner shipping, carrying capacity can be seen as one of the key resources to strive for better firm performance. The liner shipping market nowadays has entered a phase in which Liner Shipping Companies (LSCs) reap economies of scale. The concept of economies of scale has led the industry to grow by enlarging its carrying capacity and LSCs allocate more ships to offer shipping services in the global market. However, the results of enlarged capacity may be uncertain. By examining empirical data between 1997 and 2008, this paper investigates the relationship between capacity and firm performance in the liner shipping industry and attempts to use an S-curve to describe the association between capacity and firm performance in liner shipping operations. The findings suggest that the S-curve is robust. Furthermore, this study attempts to provide theoretical basis for shipping lines to determine the optimal carrying capacity.

1. Introduction

From the perspective of the industrial organization paradigm, Porter [1] summarizes a long standing tenet of industrial organization as “the industry structure determines the conduct of firms whose joint conduct then determined the collective performance of the firms in the marketplace.” It indicates a strong tie between market Structure, Conduct and Performance (SCP). According to Coase [2], SCP can be defined as “the observable structure characteristics of a market determine the behavior of firms within the market, and that the behavior of firms within a market, given structural characteristics, determines measurable aspects of market performance.” The SCP relationship was first validated by Mason’s [3] linear model. Demsetz [4] found a significant positive relationship between profit and industry concentration and argued that market share and above-average profits can be achieved through cost advantage over its rivals. Koch [5] defined market structure as “the strategic elements of the environment of a firm that influence, and are influenced by, the conduct and performance of the firms in the market in which it operates.” Other SCP empirical study includes Bresnahan [6] surveyed industrial organization studies in 1970s to 1990s. Bresnahan [6] and Corts [7] discussed alternative interpretations on market power. Market structure can be investigated through such variables as economies of scale, entry barriers, industry concentration, and product differentiation [8]. The market structure of the liner shipping industry affects the conduct of Liner Shipping Companies (LSCs) in their business operations [9]. Market conduct involves the actual behaviors of firms in a market and how the firms respond to the conditions imposed by the market structure and how they interact with rivals. Pricing policy and capacity management are significant aspects of market conduct. The performance of LSCs depends on their conduct of making such decisions as pricing and capacity level. The shipping market fluctuates from time to time. Tezuka *et al*. [10] showed that the systematic risk of Japanese liner shipping stock market increases with competition but decreases with higher market concentration. In case of unfavorable market conditions, LSCs confront intense price competition and under-utilization of fleet capacity which results in low profitability. On the other hand, LSCs may charge higher freight rate when there is a shortage of supply of shipping capacity [11].

In recent years, the liner shipping industry has gained increased attention from the government, trade associations, and global traders [12]. Song *et al*. [13] pointed out that there are two contemporary issues that need to be explored in the liner shipping area. One argument is that the LSCs face intense competition in the globalized liner shipping market. The other point is the over-capacity. The over-capacity leads to lower freight rates. As a result, the liner shipping is characterized by low profit margin due to over-capacity. The level of capacity utilization depends on the growth of containerized cargo, the speed with which existing operators introduce new and larger vessels into liner shipping service, and the level of exits of operators from the market. On the track of liner shipping research, pervious works are mainly restricted to ship operations such as optimal speed and ship scheduling (e.g., Christiansen *et al*. [14]). Various mathematical programming models and optimization techniques have been heavily developed that provided operating solutions using deterministic or stochastic models (e.g., Zhang *et al*. [15]). However, recent studies in liner shipping management are rather limited. This paper attempts to fill the research gap by investigating the relationship between capacity and market share in liner shipping as well as determining a functional specification of this relationship. In this study, we attempt to present characteristics of the liner shipping industry by investigating internal and external factors as the basic parameters of the S-curve and testing it using the empirical data from 1997 to 2008. We further attempt to determine the shape of the S-curve so as to disclose the transition from scale economies to scale diseconomies.

2. Literature review

It is well recognized that perceived growth and scale operations influence the performance of firms [16]. The organizational growth stimulates economies of scale and expansion of firm size is closely related with prestige. To remain competitive, many firms intend to strive for growth in the dynamic operating environment [17]. LSCs nowadays enlarge their firm size to demonstrate their ability to confront traditional and new challenges. For instance, large-sized operations induce an operational mechanism to facilitate cost efficiency over a high production volume [18]. Large firms are able to gain a better position to deter potential competitors from entering into the market [19]. Operating on a large-scale prompts geographical expansion and encourages the globalization of business [17]. LSCs extend their geographical coverage to attract sufficient cargo volume that allows them to reap economies of scale in vessel operations so as to diminish the unit cost of container handling [20,21]. The enhancement of capability in the liner shipping context can create a potential source of competitive advantages [22]. Apart from scale operations, many LSCs have taken initiatives to broaden and widen the range of services to enable them to exceed shippers' expectations [23]. To exploit the business opportunities, LSCs offer comprehensive shipping services such as increasing the service frequency and the number of ports of call. Indeed, many LSCs enlarge their service scope by providing a wide range of related services, including developing various logistics-related services and expanding container terminal operations internationally [24–26].

Originating from the strategic management literature, a firm gathers organizational resources and uses its resources in an optimal pattern. Capacity can be seen as one of the key resources in liner shipping operations [23]. Based on Day [27] (p. 38), capabilities are "complex bundles of skills and accumulated knowledge, exercised through organizational processes, which enable firms to coordinate activities and make use of their assets." Makadok [28] emphasized that the process of production is found to be scale optimal and fosters increasing economic returns. Economies of scale in the use of resources constitute a substantial competitive advantage of firms to gain survival and prosperity [29]. In the context of liner shipping operations, low rates of return on capital and low freight rates have stimulated the LSCs to enlarge their capacity to spread fixed unit costs and increase revenue [23,30]. Based on that, the world's mega LSCs tend to increase their carrying capacity which has intensified the characteristic of concentration of operations in the overall liner shipping industry. Since 1995, the trends of merger and acquisition have spanned across shipping firms [23]. Large LSCs acquire small LSCs with the aim to solidify their competitive position against other rivals [30]. Examples include the takeover of CP Ships by Hapag-Lloyd in 2005 (now one of the top five LSCs in the world), the takeover of P&O Nedlloyd by Maersk in 2005, and the merging of CMA CGM and Delmas in 2006. These consolidations have created an extraordinary scale of consolidation in the liner shipping industry [23,31,32]. From this perspective, returns on investment are determined by firm size.

The S-curve can be a useful tool to illustrate the revenue frontier in liner shipping. It denotes a common characteristic of a system that a quantity grows slowly, and then rapidly and finally slowly. The S-curve has been widely used. In ecology, the S-curve is used to describe the population growth (e.g., Gabriel *et al.* [33]). In marketing, the S-curve is used to model the response rate to advertising (e.g., Johansson [34]). In project management, the S-curve is used to represent the cost development along the project duration (e.g., Cioffi [35]).

3. Methodology

The analysis of this study is divided into two steps. In the first step, the S-curve is used as the theoretical basis for production frontier analysis. The S-curve is an approximation of an unknown frontier function and the accuracy of the S-curve is verified by observed data. The S-curve will therefore be used to test for the presence of both economies and diseconomies of scale in the liner shipping market. In the second step, the macroeconomic data of the liner market are considered to determine the shape of the S-curve. In this study, we explain the shape of the S-curve in view of the macro-market conditions. Insights can be achieved from a parametric model, which allows statistical testing and can be used to explain the diseconomies of scale. The concept of scale efficiency is originally developed in terms of cost function, which is not easily observable in the liner shipping operation. Following the literature of efficiency analysis (e.g., Coelli *et al.* [36]), we assume the revenue frontier mirror the cost frontier and extend the scale efficiency concept to revenue change versus scale. Similar approaches have been used in the container terminal efficiency studies (e.g., Yip *et al.* [25,26]) because the throughputs of container terminals are observable but their operation costs are not readily observable.

The first step is to estimate the parameters of the S-curve for each year. The S-curve concept is employed here with the presence of the diseconomy of scale. When the capacity q is initially introduced into the production, the revenue r is low because operators of small capacity are competing for market share. As the operator acquires more capacity, the revenue r will increase until it reaches the maximum revenue r_∞. Without loss of generality, we assume that the relationship between capacity and revenue would be described by an S-curve. The standard equation for the S-curve can be defined as [37]:

$$r(q) = \frac{r_\infty}{1 + a\exp(-bq)} + r_0 \tag{1}$$

where r is the revenue, q the capacity, r_∞ the saturation value or the upper limit at infinity, a the shape parameter, and b the scale parameter.

$$\ln\left(\frac{r_\infty}{r - r_0} - 1\right) = \ln a - bq \tag{2}$$

The shape of parameter a indicates the position of curve initialization. A small value a means that the change from scale economies into scale diseconomies occurs at a small value of capacity q. Therefore, the problem of scale diseconomies will be observed at a small value of q. A large value a delays the occurrence of scale diseconomies along the capacity q. The scale parameter b indicates the growth rate of the curve. A small value b means that the change rate of scale economies into scale diseconomies is slow. Therefore, if b is small, the interface between scale economies and diseconomies spreads over a large range of capacity q. A large value b shows a flat S-curve. In the second step, we attempt to estimate the S-curve versus macro-market data. Instead of remaining static, the liner market is dynamic over time. The liner market can be quantified by four primary components: (1) demand, (2) supply, (3) operating cost, and (4) revenue. To investigate the hypothesis, the model specification is expressed as:

$$\text{Parameters of S-curve} = f(\textit{demand}, \textit{supply}, \textit{operating cost}, \textit{revenue}) \tag{3}$$

where *demand* = seaborne trade; *supply* = new delivery, new order, and scrapping; *operating cost* = bunker price, and seamen wages; and *revenue* = freight rate. The parametric model (3) allows for statistical testing and can be used to explain diseconomies of scale.

4. Data and discussion

In this study, we mainly evaluate and measure the efficiency of LSCs. We consider the internal and external factors in examining the determinants of efficiency in the liner shipping industry. It is preferable to use empirical data to evaluate firm performance [38]. To study the internal factor, the data of total revenue and capacity of the top 20 ocean carriers between 1997 and 2008 were collated from Containerisation International. Containerisation International is highly recognized within the maritime sector as a source of invaluable insight and statistics on the container market over the last 40 years (source: Containerisation International).

To examine the external factor of liner market, the data of seaborne trade, new delivery of container vessels, new order of container vessels, scrapping of container vessels, bunker price, seamen wages, and freight rate between 1997 and 2008 were collected from the Review of Maritime Transport [39–41], Clarkson Research Studies [42], International Labour Organization (ILO) [43] and Drewry [44], respectively. Since 1968, the Review of Maritime Transport has been one of UNCTAD's flagship publications. It highlights the worldwide evolution of shipping, ports, and major transportation pertaining to liquid bulk, dry bulk, and containers. The Clarkson Research Studies offers research, statistical, and financial services to ship brokers and the maritime industry. The team of experienced researchers and analysts at Clarkson Research maintains comprehensive databases of the world's bulk, container and general cargo fleets comprising 30 000 vessels on a daily basis (source: www.clarksons.com). The ILO publishes research related to the changing nature of work and employment which brings insight and direction to policy makers. The ILO maintains integrity, independence, and high professional standards and gathers, disseminates, analyses, and processes statistical data to the public. In doing so, the ILO is able to provide timely labor statistics and accurate economic analysis, facilitating increased awareness of common problems, explaining actions and mobilizing interest (source: www.ilo.org). Drewry Shipping Consultants Limited offers a full range of economic, commercial, and technical consulting and publishing services to the international maritime industry. Manned by a research team of dedicated, highly skilled, and experienced analysts it has established comprehensive databases over three decades (source: www.drewry.co.uk).

Accordingly, these five sources provide objective data to measure our study variables, including individual liners in terms of total revenue and total capacity, seaborne trade, freight rate, bunker price, seamen wages, new delivery, new order, and scrapping (Table 1). Our research uses several quantitative analytical tools to empirically test the efficiency of liner operators. We illustrate internal and external factors as the basic parameters of the S-curve to determine the optimal carrying capacity of shipping lines. The S-curve is used widely to describe actual costs, planned spending, and the budgeted cost of work performed. The S-curve is useful in conducting a risk analysis of shipping finances by showing the altered spending rates needed to attain profitability [35]. To predict firm performance, the external variables of the liner market are considered into regression analysis.

4.1. *The S-curve*

When exhibited as a function of time, costs of projects or accumulated efforts are usually presented as an S-curve [35]. In this study, there are two main factors for consideration, capacity, and revenue, in exploring the tendency of liner shipping operations from the S-curve effect. To test the relationship between capacity and revenue, we use 12 years of data, from 1997 to 2008, gathered from Containerisation International. The empirical data of total capacity and total revenue of the top 20 liner operators are collected to plot an envelope graph. The recent consolidation among LSCs generates the S-curve effect. Between 1997 and 2008, the bigger LSCs captured a larger market share by enlarging capacity. The concentration ratio of four largest LSCs (i.e., CR4) increased significantly from 15.5% in 1997 to 32.8% in 2008 [32]. Between 1997 and 2008, LSCs enlarged their tonnage to capture more market

Table 1. Summary of independent variables.

Variables	Average (SD)
Seaborne trade (million ton)[a]	6554.5 (1017.96)
Container throughput ('000 TEU)[b]	324 417.33 (122 816.255)
Fleet capacity ('000 TEU)[b]	6850.79 (2774.07)
Delivery ('000 TEU)[c]	778.89 (403.10)
New order ('000 TEU)[c]	1641.70 (1737.29)
Scrap ('000 TEU)[c]	38.02 (31.88)
Bunker price ($/ton)[c]	330.24 (225.34)
Seamen wage (USD)[d]	5715.00 (423.59)
Freight rate ($/TEU)[e]	1356.25 (96.26)

Sources: [a]UNCTAD—"Review of Maritime Transport"; [b]Drewry—"Market Review and Forecast"; [c]Clarkson Research Studies—"Shipping Review and Outlook"; [d]International Labor Organization; [e]Drewry—"Annual Container Market Review and Forecast".
Notes: Year 1997 to 2008. The regression formula is Equation (3). The results are reported in Table 3, while only significant variables are included.

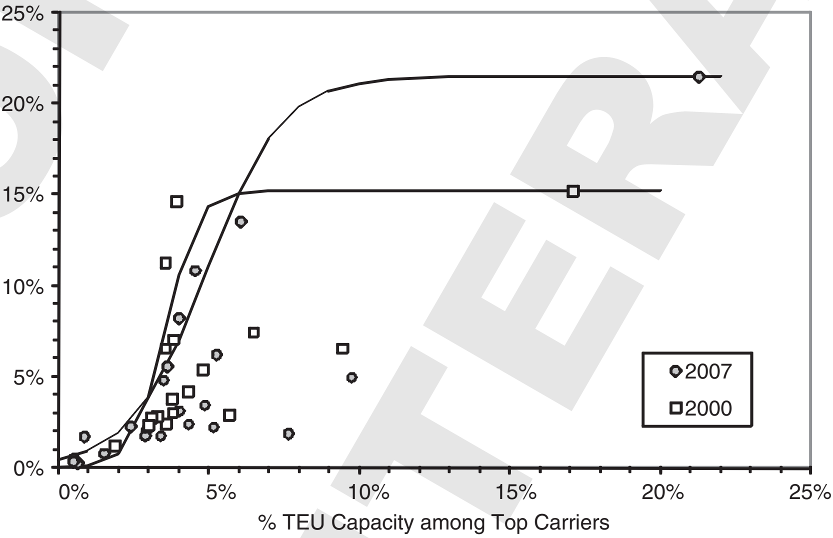

Figure 1. The relationship between carriers' revenue and capacity share.
Source of raw data: Containerization International.

share. It is noticeable that the return of liner operators is in accordance with market share. Thus, accordingly, the market players have engaged in a strategy of acquisition or expansion over the past few years. As shown in Figure 1, our findings provide strong evidence that capacity and revenue are not linear correlated. In that case, we apply an S-curve to characterize the relationship between capacity and revenue each year from 1997 to 2008. Cioffi [35] noted that the name of the S-curve stems from "the S-like shape of curve (i.e., flatter at the beginning and end, steeper in the middle)." In general, the S-curve is a form of the learning curve, which supposes that performance improvement eventually reaches a plateau [45]. The S-curve is typically applied in economic production that scale economies exhibit below optimum scale and scale diseconomies above optimum scale [36]. The S-curve describes the frontier of each capacity level that generates the maximum revenue. On one hand, LSCs are on the frontier when they are efficient. On the other hand, LSCs are beneath the frontier when they are inefficient. Yip and Lun [32] demonstrated that LSCs that occupy a capacity share between 4% and 9% are capable of attaining 8–20% of revenue share in the liner market. According to the 2008 data, it show that the optimal firm size in liner shipping is between 4% and 6% of the size of capacity share. LSCs enjoy increasing returns of scale occurring at the capacity share below 4%, whereas decreasing returns of scale existing at the capacity share beyond 5%. It follows that LSCs increase revenue without expanding their capacity under the efficient frontier. According to Equation (2), the data are fitted from year to year by liner regression analysis of $\ln(r_\infty/(r-r_0)-1)$ versus q. The intercept and the slope of linear regression line give the shape parameter $\ln(a)$ and the scale parameter b, respectively. The S-curve analysis is summarized in Table 2.

4.2. *The regression model*

The key findings are produced by regression analysis. To provide an understanding on how S-curve and market factors are associated, we carry out a parametric analysis to assess the relationships of these study factors [46]. Market factors (i.e., seaborne trade, freight rate, and scrapping) are tested with S-curve parameters.

For large values of shape parameter a and scale parameter b, the scale diseconomies are found at a large value of capacity q. The results in Table 3 show

Table 2. Results of S-curve analysis.

	Shape parameter	Scale parameter		
Year	ln *a*	ln *b*	*b*	R^2
1997	5.121	4.772	118.1	0.930
1998	4.540	4.738	114.1	0.852
1999	5.330	5.058	157.3	0.856
2000	6.875	5.260	192.4	0.782
2001	6.627	5.281	196.6	0.701
2002	9.383	5.588	267.3	0.800
2003	5.476	4.961	142.7	0.884
2004	2.472	4.459	86.4	0.711
2005	2.758	3.978	53.4	0.965
2006	3.142	4.025	56.0	0.925
2007	3.950	4.382	80.0	0.929
2008	2.814	3.642	38.2	0.902

Sources of raw data: Containerisation International.

Table 3. Results of regression analysis.

		Dependent variables	
		Shape parameter $\ln a$	Scale parameter $\ln b$
Demand	Independent variables		
	ln seaborne trade	90.91 (3.842)*	29.63 (4.623)**
	ln container throughput	−70.43 (−3.659)*	−25.49 (−5.085)**
Supply	ln Fleet capacity		
	ln Delivery	−9.24 (−7.262)**	−2.24 (−5.918)**
	ln New order		
	ln Scrap		0.17 (3.547)*
Operating cost	ln Bunker price	19.62 (5.299)**	5.62 (5.093)**
	ln Seamen wages	86.53 (3.047)*	38.47 (5.618)**
Revenue	ln Freight rate	−34.13 (−5.559)**	
	Constant	−455.8 (−1.84)	−283.67 (−5.183)**
	R^2	0.971	0.960
	Adjusted R^2	0.928	0.900
	F-statistic	22.35**	15.93**
	Akaike information criterion	1.906	−0.501

Notes: Year 1997 to 2008. * and ** significant at the 0.05 and 0.01 levels (two-tailed), respectively. The regression formula is Equation (3).

that when the operating costs increase (i.e., bunker cost and seamen wages), both parameters a and b will increase, and therefore the scale diseconomies will be found at a larger capacity q. It is common that a high setup industry has a higher value of scale economies, for example, power plants, container terminals, etc.

The shape parameter a depends on the freight rate. Given that the supply, demand, and cost are unchanged, the increase of freight rate leads to a more profitable operation. Relatively, the portion of cost reduces, and the effect of freight rate is opposite to operating cost. The sign of freight rate is therefore assumed. On the other hand, Table 3 presents that more supply of liner shipping (i.e., delivery) will introduce the scale economies at a smaller capacity q, because both parameters a and b will decrease accordingly. It is well known that more supply implies more intensive competition and a higher potential of oversupply. The effect of scrapping is to reduce the supply, and so the scale parameter b increases if supply is reduced by scrapping. Thus, the diseconomies of scale may be observed at a smaller capacity, if more supply is available.

It is surprising that the existing fleet does not have significant impact on the S-curve statistically. A possible reason is that the delivery has reflected the effect of the fleet increase. It is implicit that *Current fleet* = *Previous fleet* + *Delivery* − *Scrap*. The signs of demand variables might raise some doubts at first glance, where the sign of seaborne trade is positive but container throughput negative. Actually, the opposite signs represent the competing effects of scale economies and diseconomies. The increase of seaborne trade leads to higher values of both shape parameter a and scale parameter b. Expanding seaborne trade will encourage scale economies. The increase of container throughput implies a higher degree of coordination problems and scale diseconomies are the result.

5. Conclusions

In this study, we use a two-step approach that allows not only for frontier analysis of scale economies, but also a parametric analysis of the parameters of the frontier function. The S-curve is used to describe the frontier function and the fitness is confirmed with high values of R^2 statistic. Unlike other functions, the S-curve assumes the presence of scale economies and diseconomies. The shape and scale parameters of the S-curve have further validated with empirical data. It is found that the shape parameter mainly depends on the demand for liner shipping and the scale parameter depends on the cost of liner shipping.