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# The determinants of vessel capacity utilization: The case of Brazilian iron ore exports

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ABSTRACT

The objective of this paper is to determine the drivers behind the utilization of a vessel's cargo-carrying capacity on individual voyages. Based on maritime economic theory we propose that a vessel's capacity utilization - defined as the ratio of cargo size divided by DWT - should be positively correlated with freight rates, as poor market conditions will force vessels to compete for lower-than-optimal stem sizes. Furthermore, we propose that capacity utilization is dependent on the distance sailed, the fuel price and the value of the cargo. Using a unique data set sourced from port agent lineup reports and covering nearly 10,000 individual shipments of iron ore from Brazil between 2009 and 2014 we estimate a multiple regression model consisting of macroeconomic, route-specific and vessel-specific determinants. Our empirical results suggest that vessel-specific determinants (DWT) dominate the impact of general market conditions, with smaller vessels typically having lower capacity utilization. The impact of freight market conditions conforms to our *a priori* expectations. Our findings and modeling approach contributes to maritime environmental policymaking by enabling more accurate bottom-up estimation of emissions. The research is also crucial for improved modeling of real vessel earnings and tonne-mile demand based on observations of global ship movements from AIS data.



## 1. Introduction

Vessel capacity utilization refers to the share of a vessel's total carrying capacity occupied by paying cargo (Alizadeh and Talley, 2011a). Capacity utilization is a general concept that applies to all segments of shipping. However, the way we measure cargo carrying capacity is defined by the type of ship and may refer to, for instance, tonnes (bulk carriers), cubic meters (gas carriers), TEU (container vessels) or lane meters (RoRo vessels). Typically, the intake of light and voluminous cargoes such as containers is constrained by volume, and so capacity utilization refers to the fraction of total volume available for loading, while the intake of heavy cargoes such as coal and iron ore is constrained by weight relative to a vessel's allowed Deadweight Tonnage (DWT). A ship's DWT is typically quoted as being the maximum carrying capacity applicable under the International Load Line Regulations when floating at the Summer Load Line draught. To complicate matters, the actual density of certain cargoes (e.g. light oil products or light grains) will decide if the cargo intake on a particular trip is constrained by the available volume or weight, even for tankers and bulk carriers. In the case of container vessels, actual capacity utilization may also be constrained by vessel stability calculations (i.e. the stacking sequence and resulting centre of gravity)

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(Zerby and Conlon, 1978). To avoid some of these challenges, the theoretical exposition in our paper relate to the transport of high-density cargoes on bulk carriers, where capacity utilization can be thought of as a continuous function and the cargo intake is always weight constrained. In this case, the definition of capacity utilization is simply cargo size divided by DWT, a ratio which is sometimes also referred to as the load factor (Wijnolst and Wergeland, 1996, p. 312). We emphasize that a vessel cannot be loaded to 100% DWT utilization, as the deadweight measure also includes the weight of fuel, freshwater, supplies and crew that the vessel is allowed to carry for a particular draught.

Capacity utilization is a key input in both macroeconomic models of the freight market and microeconomic models of vessel/firm profitability. At the macro level, overall fleet productivity is determined by capacity utilization, sailing speed and ballast ratio (see e.g. Wijnolst and Wergeland, 1996). The higher the capacity utilization, the more transportation work a given fleet will produce per time unit. Conversely, low average capacity utilization implies there is slack or spare capacity available on the supply side. At the micro level – be it an individual voyage or an individual company – capacity utilization will have a large impact on the profitability and unit transport cost. This is because most costs can be taken as fixed once a voyage has been accepted or, in the case of liner shipping, a string of vessels have been employed with a defined route and service frequency. To illustrate the importance of capacity utilization for the economics of bulk carriers, Fig. 1 shows the relationship between capacity utilization and timecharter-equivalent (TCE) vessel earnings and transportation cost, respectively. For the purpose of illustration we here use the Capesize voyage from Rotterdam via Tubarao to Qingdao, with fuel and freight market prices as of 26th June 2015 and Baltic Exchange (2015) route assumptions. The unit transport cost refers to the $/-tonne breakeven rate when chartering the vessel at the prevailing tripcharter ($/day) rate. For the sake of simplicity we have here ignored the second-order effect caused by the dependency of fuel consumption on cargo size, i.e. the impact of a higher draught on fuel consumption. From Fig. 1 it is obvious that sailing with very low capacity utilization is detrimental to profitability. Indeed, there will be a point of utilization below which accepting the cargo becomes uneconomic – in this example below 45%.

From a policy point of view, capacity utilization is a key input in the bottom-up estimation of air pollution from ships. The reason is twofold: (i) it directly affects the fuel consumption and air emissions as the main determinant of the draught (displacement) of a vessel, and (ii) it affects the level of emissions per tonne mile, both as a measure of the amount of cargo onboard and a determinant of the fuel consumption. In order to get a true picture of energy use and related emissions per tonne-mile, particularly in the comparison between land and sea-based transportation modes, it is crucial to use the true cargo carried rather than DWT capacity (Hjelle, 2011). In this context, low capacity utilization would jeopardize the comparative advantage of maritime transport alternatives, and it is therefore a crucial variable to monitor and understand for policy makers. As a related point, poor capacity utilization would question the economic and environmental sustainability of the mega-ships currently in operation and under construction in the container liner industry. In general, lower capacity utilization will imply higher emissions per unit of transportation work, all else equal.

As a related policy issue, capacity utilization is also closely tied to the cost of maritime transportation in international trade. For instance, when raw materials are carried on vessels hired on a timecharter ($/day) basis, the real unit cost per tonne of cargo is inversely related to utilization. The use of part loading (low utilization) will, all else equal, therefore lead to higher transport costs and lower international maritime trade (Korinek and Sourdin, 2010; Valentine et al., 2013). More generally, higher capacity utilization of all vessels will increase the available supply of transportation by the existing fleet and reduce transports costs (freight rates) by exploiting economies of scale in general (see, e.g. Hummels, 2007, for a related discussion).

Despite the importance of capacity utilization at the micro level in regards to environmental policy, the true cost of international trade and economic sustainability, there are no published empirical studies on its determinants and dynamics. This is likely due to the difficulty in obtaining reliable voyage-specific data on cargo sizes. Our paper is a first attempt at filling this gap in the literature. We contribute to the literature by providing the first theoretical exposition and empirical analysis of the micro- and macroeconomic determinants of capacity utilization in bulk shipping markets. Additionally we investigate this important issue by using an entirely new set of data on cargo sizes from port agents.

The remainder of the paper is organised as follows: Section 2 reviews the relevant literature on capacity utilization, Section 3 presents the theoretical basis for our model and variable selection, Section 4 presents our data and descriptive statistics, Section 5 presents our empirical results and Section 6 concludes with suggestions for future research.

## 2. Literature review

While it is clear from the introduction that capacity utilization is a key driver of economic and environmental performance in the maritime supply chain, we do not yet have a good understanding of its determinants. Although capacity utilization is an input in most standard supply/demand models and emissions accounting models, it is often assumed to be of a certain functional form based on industry "rules of thumb".

Wijnolst and Wergeland (1996, p. 314) states that "the load factor can theoretically become as high as 0.975, will in practice hardly ever be higher than 0.95, but may come as low as 0.65 if demand is very low and part loading and multi porting are common phenomena". Smith et al. (2013) suggest that when the freight market is in a state of overcapacity, operators are forced to compete harder for cargoes, resulting in a willingness to accept a greater number of part-load cargoes. Both sources thus point to a positive relationship between freight market conditions and capacity utilization. It is important in this con-

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