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Strategic maritime container service design in oligopolistic markets

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ABSTRACT

This paper considers the maritime container assignment problem in a market setting with two competing firms. Given a series of known, exogenous demands for service between pairs of ports, each company is free to design liner services connecting a subset of the ports and demand, subject to the size of their fleets and the potential for profit. The model is designed as a three-stage complete information game: in the first stage, the firms simultaneously invest in their fleet; in the second stage, they individually design their services and solve the route assignment problem with respect to the transport demand they expect to serve, given the fleet determined in the first stage; in the final stage, the firms compete in terms of freight rates on each origin–destination movement. The game is solved by backward induction. Numerical solutions are provided to characterize the equilibria of the game.

1. Introduction

Over the last 50 years, containerization has grown to account nowadays for roughly 70% of total deep sea trade (by value) and it is now a key component of the global economy. The resulting standardization of freight handling processes has enabled quick and efficient cargo movements across transport modes and has relied on the concept of transshipment to provide global coverage. This involves the use of multiple services to establish connectivity between ports that are not otherwise served by direct maritime links. As such, the global liner shipping network has adopted a hub-and-spoke structure, whereby there is a strong incentive for liner services to include visits to heavily connected ports (such as Singapore, Rotterdam and Hong Kong) in their rotations.

This structure, combined with the volatile and competitive nature of the ports and shipping markets, has led to intricate flows patterns that can often be difficult to predict. The development of accurate flow models would not only assist shipping lines in the deciding what services will be provided, but could also prove useful to other relevant stakeholders. These include port operators, governments and international organizations, who could use such models to allocate investments, perform strategic/operational planning, and design future policies.

One of the earliest works to model maritime container flows is the Container World project (reviewed in Newton, 2008), while Perrin et al. (2008) developed one of the earlier macroscopic container assignment models. At the same time, much

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research has focused on the empty container management problem, which occurs due to the effects of trade imbalances, predominately (e.g., between Western and Asian markets). Previous work by Bell et al. (2011, 2013) focused on the development of a container flow assignment framework that acknowledges transshipment operations and capacity constraints in the ports and vessels involved. The resulting optimization algorithms remain linear in nature, are built around the frequency-based structure of liner shipping services and seek to minimize aggregate container travel durations or costs, respectively. Both techniques are capable of simultaneously addressing full and empty container flows – in the past the latter have mostly been examined in isolation and as part of the empty container repositioning problem (Song and Carter, 2009). Given their linear nature they have modest computational requirements, therefore making them particularly attractive for application in large problem settings that involve hundreds of ports and services.

Following the seminal contributions by Agarwal and Ergun (2008) and Shintani et al. (2007), in the last few years a number of studies have jointly addressed the issues of network design and container flow assignment, taking into account cargo routing and empty container repositioning (e.g., Imai et al., 2009; Song and Dong, 2013; Mulder and Decker, 2014). Meng et al. (2014) provide an interesting overview of this fast-growing literature in the general context of studies on containership routing and scheduling. Brouer et al. (2014) also design a benchmark suite for liner shipping network design. However, all these studies keep the perspective of a single shipping line or alliance and do not deal with the consequences for freight rates or routes of competition between shipping lines or alliances.

The aforementioned work provides important insights into the forces that drive the global flow of containers. However, the existing models still fail to take into account some crucial features of the global shipping market such as: the elasticity of freight demand with respect to the economic conditions (e.g., travel time and fees) that prevail in the shipping industry at any given moment; and, on the supply side, the effects of strategies adopted by groups of players (e.g., shipping lines or alliances) in the same shipping market.

As regards the effects of competition on service network design, the economic theory of industrial organization highlights two possible outcomes (Tirole, 1988). If competing firms provide services of similar quality (e.g., service reliability) and features (e.g., planned delivery time), competition would take the form of strong price war, reducing profits and, in some cases, preventing the market from finding a stable configuration (or medium-term equilibrium). On the other hand, if competing shipping firms are able to determine some form of service differentiation they may reduce the strength of competition and, in this way, increase profits (which nevertheless will remain lower than in the monopolistic case). This case is potentially relevant for the shipping industry, given that firms are able to offer different service networks that, in turn, imply diverse delivery times and service features[1]. The policy implications of the two scenarios are quite different: if competition is strong, no regulation of the shipping sector is desirable, given that the market tends to determine the lowest possible prices for shippers; conversely, if competition is weak, prices and profits would tend to increase, and a regulatory remedy could be desirable if the barriers to market entry prevent new shipping lines filling unmet consumer demands.

The model introduced in this paper seeks to address this gap in academic literature, by developing an algorithm that could be used to determine an optimal set of liner services, given the presence of a competing shipping firm. The resulting model has game-theoretic elements, whereby the choice of services to be offered by each shipping line or alliance reacts to the actions of its competitors. Container flow assignment is integral part of this process, as it is used to establish how the market would respond to the simultaneous provision of routes by competing parties.

The types of service considered in the model follow established liner shipping trends, where vessel services comprise a looped sequence of port calls (commonly referred to as a port rotation). The resulting model takes into account revenues deriving from a demand for transport services that is distributed between firms in accordance to service costs. The latter include fees charged by the firm operating the chosen service as well as the opportunity cost of travel times. Empty container repositioning is retained in the container assignment model.

The key actors of the model are two firms (i.e., shipping lines or alliances) that seek to maximize their weekly profits by operating in a given region with known transport demands for full containers among a set of ports. To meet this objective, they both aim to operate sets of liner services, each being a circular tour of ports with a given frequency and capacity. Respective fleet sizes constrain the services that each firm is capable of offering.

The model acknowledges the practice of transshipment in the maritime industry, as the possibility exists for a firm to satisfy demand between two ports that are not served by the same tour. This is achieved by identifying two services that include the origin and destination port, respectively, that also intersect at some intermediate location. In modeling terms, this is achieved by simultaneously representing each service in three forms:

- as a sequence of port visits (in a closed loop form);
- as a sequence of links (journeys between two adjacent ports in the service);
- as a sequence of legs (a pair of any two ports in a service, between which travel is possible).

In our analysis set N contains a series of possible container routes. Each route n consists of a set of links L_n. Each link l within L_n represents a trip between two consecutive ports in the same route. For each route n it is possible to obtain a set of legs A_n, representing every single container journey that could be made using this route. The relationships among ports, links and legs are illustrated in Fig. 1.

[1] We can interpret the scenarios forms of monopolistic competition where the elasticity of substitution between services provided by different firms is infinite (first scenaro) or finite (second scenario).