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Optimal bunkering contract in a buyer–seller supply chain under price and consumption uncertainty

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ABSTRACT

Bunker fuel constitutes about three quarters of the operational costs for liners. A strong effort is justified to define operational conditions and management strategies to minimize fuel-related costs, especially if the variability of fuel price is considered. Fuel sellers and liners use contracts to be guaranteed a refuelling quantity and control bunker price. We propose a game theory based approach to examine and optimize the parameters of a realistic bunkering contract. Under the proposed settings, the supplier and the buyer establish the bunker quantity and the price to maximize the expected profit and minimize the expected refuelling cost, respectively.

1. Introduction

For shipping companies, a noticeable percentage of the variable operating costs are imputable to bunker fuel (Fagerholt et al., 2009; Ronen, 2011). If also the recent regulations on the emissions (MARPOL Annex VI (Federation, 2013) are considered, the two facts together call for the need to establish structured and efficient operational policies and management strategies to optimize the use of bunker fuel (Schinas and Stefanakos, 2012). Moreover, in the case of *liner* shipping companies, policies can be particularly effective, since purchasing of bunker fuel can be planned some months ahead, as the vessels are sailing on fixed schedules, as opposed to tramp and other types of shipping (Farina et al., 2013; Yao et al., 2012; Wang et al., 2013b). Nevertheless, the design of an optimal fuel management strategy (both at operational as well as tactical level) is far from being trivial mainly due to the remarkable variability of fuel price (both with respect to time as well as ports) and the consumption variability due to the operational strategies chosen by the carriers and the weather conditions (Besbes and Savin, 2009).

Fig. 1 reports the bunker index (representing the Average Global Bunker Price – AGBP – computed over all the individual port prices published on the Bunker Index website, http://www.bunkerindex.com/) during the period March 2009–December 2013. An increasing trend in the bunker prices is apparent as well as an increase in variability (a measure of such variability is the proportion between the Low and High prices). It is apparent the high fluctuation of the prices. Currently, we are observing a spectacular fluctuation of the fuel price that is experiencing an important decline. Prices from March 2014–May 2014 (data from www.bunkerindex.com, for 380 CST fuel type, and reference index BIX-380 CST) were on an average of 625.734 US$/ton with a standard deviation 3.457 US$/ton, a minimum average price over the ports considered equal to 318.222 US$/ton with a standard deviation of 9.259 US$/ton and a maximum price 755.089 US$/ton with a standard

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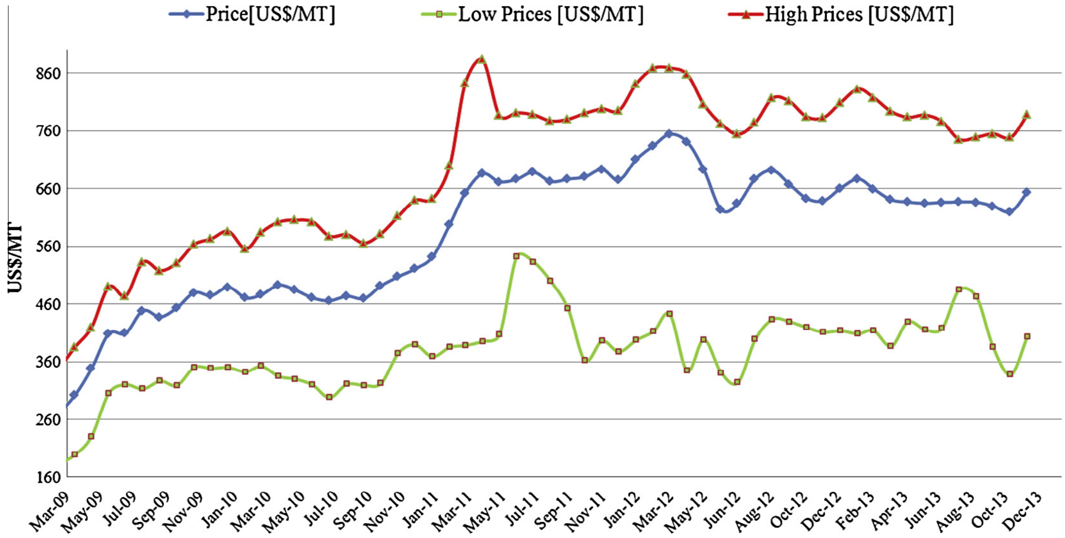

Fig. 1. Bunker Index (BIX), minimum and maximum monthly BIX value in the period March 2009–December 2013 (fuel type 380 CST). *Source:* http://www.bunkerindex.com/.

deviation 6.32 US$/ton. In Singapore, the price in the first week of May 2014 was on an average of 586.6 US$/ton after having dropped to 450.67 US$/ton at the beginning of 2014. These data provide a strong motivation toward the design of strategies to control the price variability.

In fact, bunker providers and liner companies sign agreements on bunker purchase in order to protect themselves against the depicted behavior of the price. In this paper, we look at the class of contracts with a single product supplier and we want to establish optimal price and quantity conditions while considering uncertainty of the bunker prices and consumption. We refer to this problem as the bunker contract design problem. Several critical aspects challenge the formulation and solution of the bunker contract design problem: (1) to correctly define the contract design problem, buyer and seller need to be simultaneously considered in the model, (2) fuel is an indirect product, which is not sold by the buyer (liner), i.e., its supply does not generate direct profits, (5) if a real contract is considered, the problem of formalizing the cost function is not trivial.

In order to account for the perspective of both buyer and seller, a game theoretical framework is proposed, where the players are the buyer and the seller and the payoff function is the cost (profit) resulting from the application of the agreement. The game based model provides a quantitative support to the decision makers in establishing the contract parameters accounting for both buyer and seller expected loss and revenues, respectively (Esmaeili et al., 2009; Dong and Zhu, 2007).

Game theory has seldom been proposed in the maritime literature. We can find applications of this methodology as a means to analyse competition as well as cooperation between ports (Anderson et al., 2008; Song and Yeo, 2004), to investigate the opportunity for alliances among liner shipping companies (Song and Panayides, 2002; Panayides and Cullinane, 2002), to evaluate the opportunity of introducing new service routes (Agarwal and Ergun, 2010; Zhang et al., 2005; Wang et al., 2013a, 2013). Extensive use of game theory can also be found in the airline literature (Hansen, 1990; Gaertner and Klemisch-Ahlert, 1992). However, to the knowledge of the authors, this approach has not been proposed for contract analysis in the maritime sector and, more generally, the literature related to contract analysis, in this domain, is scarce (Plum et al., 2014).

The results of the game theory model we propose show how the optimal contract parameters are influenced by both location and variance of the market prices and fuel consumption. Several scenarios are tested proving how the different contract terms can be used by the buyer and the seller to protect themselves against price and fuel consumption uncertainty.

The remainder of this paper is structured as follows: Section 2 provides a review on the related contracting literature including the background to introduce the specific contract which will be the subject of this study, highlighting the contributions with respect to the related literature. Section 3 describes the problem of interest and the related analytical model. Section 4 presents the game model. Section 5 presents the numerical experiments and results are commented. Finally, Section 6 draws the conclusions for the paper.

2. Literature review

Christiansen et al. (2007) performed a comprehensive literature review observing the growth of research interest in OR-based maritime transportation. Within this broad research field, bunkering related issues have recently received increasing attention (bunker fuel price forecast, bunkering plan, bunker fuel consumption, etc.). Ronen (1982) analyzed the trade-off between fuel savings through slow steaming and the loss of revenues due to the resulting voyage extension. He presented