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Fleet replacement decisions under demand and fuel price uncertainties

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ABSTRACT

This paper proposes a real option model to investigate the fleet replacement timing decisions when a shipowner faces uncertain demand on various routes and uncertain fuel prices (both MGO and LNG prices). A multi-option least squares Monte Carlo simulation algorithm is utilized to find the replacement probabilities in future years and the expected NPVs of the cost savings after the replacement. The proposed model is applied to a chemical tanker shipping company. The case results indicate that the shipowner should replace all of his diesel-fuelled vessels with dual-fuelled vessels at one time, rather than replacing them one-by-one. Moreover, we compare the performance of two possible government policies, the vessel subsidy policy and the fuel subsidy policy. The sensitivity analysis indicates that in our case, the shipowner prefers the vessel subsidy policy, which brings him more cost-savings and allows him to make the earlier replacement decision. Alternately, the fuel subsidy policy is suitable for routes with a larger turnover volume if governments wish to see the more obvious policy feedbacks.

1. Introduction

Shipowners currently face strict emission control. To comply with the 0.1% sulfur limit in the emission control areas (ECAs) after 2015, three alternatives can be used: switching to low sulfur fuel, installing an exhaust gas scrubber or installing LNG-compatible machinery (Acciaro, 2014b; Patricksson et al., 2015). Among them, the use of LNG-compatible vessels has recently become more promising due to the decrease of LNG prices. However, this plan has a significant upfront cost, and its benefit heavily depends on the uncertain price advantages of LNG compared to marine gas oils (MGO). Alternately, uncertain future shipping demand is another "X factor" that affects the use of new energy vessels. Therefore, whether and when to replace their diesel-fuelled fleet with the new energy vessels are the crucial problems encountered by shipowners.

In this paper, we use a real option approach to study the fleet replacement timing decisions when a shipowner faces uncertain demand on various routes and volatile fuel prices (both MGO and LNG prices). We try to provide shipowners with management insights and governments with policy implications when they face dynamically uncertain contexts. Specifically, we aim to explore the following questions: (1) How can a shipowner's fleet replacement decisions be analyzed if the future demand on routes and fuel prices are uncertain and dynamically volatile? (2) How can the impacts of parameter changes, e.g., cargo demand and fuel price volatilities, on shipowner fleet replacement decisions be evaluated? (3) How can the performance of government policies (e.g., the subsidy for building new energy vessels or the subsidy for using LNG fuel) be compared under different scenarios? From the results of our model, not only can shipowners estimate their fleet replace-

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ment probabilities in future years and the expected fleet cost savings after replacement, but governments can also evaluate the impacts of their related policies.

Our work contributes to the fleet replacement problem under environmental compliance in the following two aspects.

First, our research can support shipowners in making appropriate decisions regarding fleet replacement, especially when they have heterogeneous vessels and face uncertain cargo demand on routes and volatile fuel prices. In a dynamically uncertain context, shipowners are confronted with the timing of their fleet replacement, i.e., either vessels should be replaced now or replacement should be deferred to the future. Moreover, it is more difficult for shipowners to make such decisions when they operate heterogeneous vessels because the benefits after the replacement are different for various types of vessels. Therefore, the replacement order has significant impacts on the final decisions. In our paper, the real option approach is used to investigate shipowners' tradeoff between obtaining the present cost savings and the deferral option value. The fleet replacement problem is transformed into an optimal stopping problem. Moreover, we take into account the option value of the replacement order, which is very crucial to the replacement decisions for heterogeneous vessels, and the multi-option least-squares Monte Carlo simulation (LSM) algorithm is developed to find the option value and the fleet replacement probabilities in future years for the best replacement plan.

Second, our sensitivity analysis based on a real chemical tanker shipping company can provide a sample for governments to investigate their policy impacts on shipowners' fleet replacement behavior. According to the policy practice proposed by the Ministry of Transport in China, we summarize two possible policies: the vessel subsidy policy and the fuel subsidy policy. We perform sensitivity analysis based on the wide ranges of the parameters. The results of our case study reveal that the shipowner prefers the vessel subsidy policy, which brings him more cost savings and enables him to make earlier replacement decisions. Alternately, the fuel subsidy policy is suitable for routes with a higher turnover volume,[1] if governments wish to see the more obvious policy feedback. Although our policy comparisons rely on a specific case study, the results can still provide useful policy implications to governments when they make policies to encourage shipowners to comply with stricter environmental regulations.

The rest of this paper is organized as follows: Section 2 provides a review on related literature. Section 3 describes the problem and proposes the model. In Section 4, we apply our model to a chemical tanker shipping company to investigate its fleet replacement decisions, and we analyze the impacts of different government policies. Conclusions and possible directions for future research are presented in Section 5.

2. Literature review

The related literature can be categorized into three main streams: literature on fleet deployment and replacement (or renewal), energy-efficient maritime transportation, and real option analysis in shipping.

There is much literature on the traditional fleet deployment and replacement (or renewal) problem. Some survey papers (Christiansen et al., 2013; Pantuso et al., 2014) provide comprehensive reviews on this issue. However, most studies investigate this problem in a deterministic setting. For the context of uncertainty, some papers address stochastic cases by replacing the uncertain data with its average or extreme values (e.g., Jaikumar and Solomon, 1987; Crary et al., 2002). Only a few papers explicitly consider uncertainty in their models, using stochastic programming (Meng and Wang, 2010; Meng et al., 2012; Schinas and Stefanakos, 2012; Dong et al., 2015; Pantuso et al., forthcoming), robust optimization (Alvarez et al., 2011), and simulation (Fagerholt et al., 2010; Shyshou et al., 2010; Halvorsen-Weare and Fagerholt, 2011; Song et al., 2015). Our paper differs from these studies in the following ways. In our paper, we consider a fleet replacement problem when the demand on routes and the fuel prices are uncertain, especially with nonstationary stochastic processes. Therefore, a shipowner's fleet replacement decisions are subject to changes year-by-year. In other words, the value of decision flexibility under uncertainty should be measured. We analyze the option to defer the fleet replacement and assess the value of postponing the replacement decisions. Moreover, we investigate the fleet replacement problem under environmental compliance and discuss the impacts of different government policies on shipowners' fleet replacement outcomes.

Energy-efficient maritime transportation studies have attracted much attention in recent years. Psaraftis and Kontovas (2013) have provided an excellent survey on the speed optimization models for energy-efficient maritime transportation. In addition, Schinas and Stefanakos (2012) used a linear stochastic programming model to estimate the cost impact of the sulfur limits on the increase of operating expenses of ships. Fagerholt et al. (2015) investigated the impacts of stricter emission limits in ECAs on the speed and routing decisions. Patricksson et al. (2015) proposed a stochastic programming model to examine a shipping operator's fleet renewal problem with regional emission limits. Compared to these papers, our paper considers the value of postponing the fleet replacement decisions, as well as the value of reordering the fleet replacement sequences.

Real options analysis (ROA) is a powerful tool to address the flexibility in an investment decision (Dixit and Pindyck, 1994). There are many applications in ship investment (e.g., Andersen, 1992; Goncalves, 1992; Dixit and Pindyck, 1994; Bendal and Stend, 2005; Sødal et al., 2008, 2009; Gkochari, 2015). However, they do not take into account the environmental compliance and the impacts of related government policies on shipowners' investment decisions.

[1] Turnover = shipping volume ∗ voyage distance.