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Stable vessel-cargo matching in dry bulk shipping market with price game mechanism

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ABSTRACT

This paper proposes a model of stable vessel-cargo matching with price game mechanism in the dry bulk shipping market. The research aims at mimicking the bid of disadvantaged participants in the process of matching preferred objects. The matching equilibrium and price equilibrium are formulated between the shippers and carriers. A price game mechanism based Gale-Shapley algorithm is developed. Three scenarios of market dominated by shippers, market dominated by carriers, and equilibrium market are discussed in computational experiments. It is showed that if disadvantaged participants bid with the price game mechanism, they may gain more surpluses even in the negative position.

1. Introduction

1.1. Backgrounds

Dry bulk shipping market is an important part of international shipping market. At the end of Aug, 2015, the total deadweight tonnage of the world dry bulk shipping fleet is 757.2 million dwt, equivalent to 43.39% of the world's shipping fleet in deadweight. The dry bulk shipping market has witnessed the prosperity and the recession in recent years mainly due to the boom and the slowdown of world's economic. The Baltic Dry Index, a unique indicator of international dry bulk shipping and trade, decreases from 11,793 on May 20, 2008 to 317 on Jan 29, 2016. The cyclical fluctuations in the dry bulk shipping market are caused by the imbalance of supply and demand.

The imbalance of supply and demand forms the market dominated by shippers or carriers. In the shippers' dominated market, the disadvantaged participants are defined as carriers, while the disadvantaged participants are defined as shippers in the market dominated by carriers. However, whatever kind of market is, the participants in the negative position should take freight rate as a lever to survive. In the prosperous market, where vessels are in short supply, shippers compete without foreword to prevent the cargoes being rejected by carriers. The freight rate is driven up in the competition until the cost of shipping exceeds the cost of other alternative transport modes. When the market is depressed, there are too many vessels. The carriers compete with other homogeneous carriers, having to keep the freight rate down. Extremely, the freight rate bid by the carriers will be zero or negative. The trade behavior is complicated and even irrational. Thus an important decision of

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the participants in the negative position is to proceed the price game with homogeneous competitors. The price game tailored to different scenarios mimics how the disadvantaged participants match their preferred objects and keep the benefits.

1.2. Literature review

There are a number of literatures dealing with the selection criteria for carriers. But the literature existing for dry bulk shipping market is limited. The subject of carrier selection is reviewed by Keller (1996) and Meixell and Norbis (2008). Gibson et al. (1993) interviewed diverse industrial shippers and 75% of the respondents thought on-time performance history. The quality of service and the availability of equipment were the most important criteria they considered. Lu (2003) classified service attributes into six critical service factors which were timing related services factor, pricing services factor, warehousing services factor, sales services factor, door-to-door services factor and information services factor. Door-to-door services and information services factors were eliminated by correlation analysis. Lagoudis et al. (2006) used service, quality, cost, time to identify the total created value which was calculated by multi-attribute utility theory. They found that time was the lowest value contributor for liner, dry bulk, liquid bulk and specialized sector. Meixell and Norbis (2008) analyzed the transportation mode choice and carrier selection based on a comprehensive literature review. They demonstrated that the cost and transit time were usually taken as the primary criteria by the shipping company. Kannan et al. (2011) found that low freight and pricing flexibility were the two important criterion among the 45 criteria from the Indian shippers' point of view. Gifts and compliments, online booking, physical facilities, professional appearance and trade announcements weighed with 0.10 percent importance were the five least important criteria. Besides the cost and service factors, Jia et al. (2015) investigated the environmental criteria in the process of selecting a shipping carrier. In their study, the ability to provide environmental friendly packaging was the most influential one of the 17 criteria environmental certification. In the shipping market, carrier selection emphasized cost most in the early stage, and then service and environment were focused by the shippers. Moreover, shippers in different countries had different criteria to select carriers. The criterion which was the most important in one country may be common in other countries.

Considerable studies have been performed on the subject of two-side matching. In 1962, Gale and Shapley (1962) pioneered marriage problem and the stable assignments where the agents had their own preferences over the agents on the opposite side. Later research on stable matching and matching algorithm was studied. Extending the work of Gale and Shapley, McVitie and Wilson (1970) examined the stable two-side matching when the set of agents were unequal. They proved that an agent unmatched in any stable matching would be unmatched in all the other stable matching solutions. Shapley and Shubik (1971) transformed the assignment problem into linear programming, and illustrated the structure of the core. Roth (1984a, 1989) studied the substitutable preferences. Then he modelled the two-side matching with incomplete information where agent may not know other's preferences. Alkan and Gale (2003) developed the generalized form of the Gale-Shapley algorithm. In their study, a lattice was gotten in the stable matching when preferences satisfied the size monotonicity. Kamiyama (2013) proved the existence of a stable and Pareto efficient matching. A new approach is proposed to find the solution by computing a rank-maximal matching. However, the strategic behavior of participants could not be ignored in the two-side matching. The problem of matching and price equilibrium began to be paid attention. Bulow and Levin (2006) randomized the interval of salaries the firm offered to the workers prior to the matching. In the labor market, a worker's ability determined his wage level. A company did not set a higher wage level for the worse worker. They showed that the wage was compressed in the price equilibrium. The companies got additional surpluses while the workers' wages fell relative to any competitive equilibrium. Schwarz and Yenmez (2011) studied the median stable matching with wage in the two-sided matching market and proved the existence of it. González-Díaz and Siegel (2013) relaxed the assumption of symmetric linear costs in Bulow and Levin (2006). The hospitals could use non-interval bidding strategies with non-linear and symmetric cost. The competition was less localized in their study. Azevedo (2014) built an equilibrium model for imperfectly competitive two-sided matching market. Comparing the uniform and personalized wages, he found personalized wages yielded higher efficiency. Agarwal (2015) estimated preferences in new method in matching market. The results showed that salaries in a competitive equilibrium were less than the marginal product of labor. Han and Yamaguchi (2015) focused on the matching between the heterogeneous job and heterogeneous worker. The wage difference reflected both the compensating wage differentials and the difference in the productivity occupied on the jobs by workers. They formed a match only when the wage, reflecting the net value of the two sides' characteristics, was agreed by a firm and a worker.

The two-side matching have been applied in many fields: stable marriage problem (e.g. Zhou, 1991; Teo et al., 2001; Drgas-Burchardt and Świtalski, 2013; Holzman and Samet, 2014), hospital-resident matching (e.g. Roth, 1984b, 1986; Roth and Peranson, 1997; Crawford, 2008), roommate problem (e.g. Ronn, 1990; Irving and Scott, 2007; Chung, 2000; Morrill, 2010; Klaus et al., 2010) and supply-demand matching problem (Boon and Sierksma, 2003; Bando, 2012; Han and Yamaguchi, 2015). But application of two-side matching in transportation is not wide, especially for shipping market. Janssen and Verbraeck (2008) dealed with the internet-based matching in the transport market. They used simulated agents to model the trading situation instead of analytic methods. Demand and supply were matched to reduce negative effect. He et al. (2015) studied the equilibrium assignment between the parking spaces and the vehicles. It was ensured that the parking competition solution was also system optimum by introducing price vector. And a global optimum solution procedure was proposed to get a robust price which optimized the performance of worst-case. Thus, most studies tailored to dry bulk shipping market are focus on the investment, freight, supply and demand analysis (Gkochari, 2015; Xu et al., 2011; Alizadeh and Talley, 2011). Few studies investigate the matching problem of vessel and cargo.