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Supply chain network competition in price and quality with multiple manufacturers and freight service providers

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ABSTRACT

In this paper, we develop both static and dynamic supply chain network models with multiple manufacturers and freight service providers competing on price and quality. The manufacturers compete with one another in terms of price and quality of the product manufactured, whereas the freight service providers compete on price and quality of the transportation service they provide for multiple modes. Both manufacturers and freight service providers maximize their utilities (profits) while considering the consequences of the competitors' prices and quality levels. Bounds on prices and quality levels are included that have relevant policy-related implications. The governing equilibrium conditions of the static model are formulated as a variational inequality problem. The underlying dynamics are then described, with the stationary point corresponding to the variational inequality solution. An algorithm which provides a discrete-time adjustment process and tracks the evolution of the quality levels and prices over time is proposed, and convergence results given. Numerical examples illustrate how such a supply chain network framework, which is relevant to products ranging from high value to low value ones, can be applied in practice.

1. Introduction

Manufacturers and freight service providers are fundamental decision-makers in today's globalized supply chain networks as products are produced and distributed to businesses and consumers, often traveling great distances via multiple modes of transportation. The decisions that the firms make affect the prices and quality of products as well as that of the freight services provided, which, in turn, impact their own profitability. It is well-known today that success is determined by how well the entire supply chain performs, rather than the performance of its individual entities. Quality and price have been identified empirically as critical factors in transport mode selection for product/goods delivery (cf. Floden et al. (2010), Saxin et al. (2005)), and the references therein). Quality has also become one of the most essential factors in the success of supply chains of various products, including food and agro-based products, other perishable products such as blood, pharmaceuticals, medical nuclear supply chains, durable manufactured products, including automobiles, high tech products, such as microprocessors, and even services associated with the Internet. Although the term quality in many freight studies suffers from a somewhat vague definition (cf. Meixell and Norbis (2008 for a discussion)), it, typically, encompasses factors such as on-time deliveries, reliability, frequency, and risk of damage (see also Danielis et al. (2005) and Zamparini et al. (2011)).

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The growth of intercontinental multi-channel distribution, containerization, and direct to business and direct to customer shipping has led to fierce competition among freight service providers who are subjected to pricing pressures and increased expectations to handle more complex services (Hakim, 2014; DHL, 2014). To maintain their competitive edge, freight service providers are increasingly focused on positioning themselves as more than just a commodity business. The providers may offer flexibility to meet customer needs of safety, and/or traceability and, furthermore, differentiate themselves from the rest of the competition, thereby migrating towards being more value-oriented than cost-oriented (Bowman, 2014; Glave et al., 2014). The quality of service is driving logistics performance in both developed and emerging economies (Arvis et al., 2014). Clearly, quality in freight service is gaining in importance.

Increasingly, tough customer demands are also putting the transport system under pressure. The online retailer Amazon.com recently submitted a patent (United States Patent, 2013) for anticipatory shipping and speculative shipping, meaning that, based on advanced forecasts of customer behavior (previous purchases, behavior during homepage visits, demographics, etc.) they actually ship the products before the customer orders it! The product is shipped towards a region where a purchase is expected and is redirected during transport when the order is placed, thus, allowing almost instant deliveries (Bensinger, 2014). Transport owners that cannot offer the desired level of quality are forced to leave the market, as was the case when the intermodal company CargoNet withdrew from the Swedish rail market, claiming unreliable infrastructure as one of the main reasons (Floden and Woxenius, 2013).

Some of the pioneers in the study of product quality competition include: Akerlof (1970), Spence (1975), Sheshinski (1976), and Mussa and Rosen (1978), who discussed firms decisions on price and quality in a quality differentiated monopoly market with heterogeneous customers. Dixit (1979) and Gal-or (1983) initiated the study of quantity and quality competition in an oligopolistic market with multiple firms, where several symmetric cases of oligopolistic equilibria were considered. Brekke et al. (2010) investigated the relationship between competition and quality via a spatial price-quality competition model. Nagurney and Li (2014a) developed a dynamic model of Cournot–Nash oligopolistic competition with product differentiation and quality competition in a network framework. Further contributing to this work, Nagurney et al. (2014) proposed a spatial price equilibrium model with information asymmetry in quality in both static and dynamic versions. Others who have added to research on the topic of quality competition in general include: Ronnen (1991), Banker et al. (1998), Johnson and Myatt (2003), and Acharyya (2005).

In this paper, we focus on the development of game theory models in both equilibrium and dynamic settings. We consider a supply chain network with multiple manufacturers and multiple freight service providers handling freight transportation. The decision-makers at each echelon compete in prices. Quality of the product is traced along the supply chain with consumers differentiating among the products offered by the manufacturers. Also, quality of freight service providers is accounted for in the model and the providers are shown to be competing on both price and quality. Heretofore, the integration of price and quality competitive behavior with both manufacturers and freight service providers has not been examined in a rigorous theoretical and computationally tractable framework.

Our framework is inspired, in part, by the work of Nagurney et al. (2013) and Saberi et al. (2014). The latter proposed network economic game theory models of service-oriented Internet architectures with price and quality competition occurring between content and network providers. Here, we go further in that we allow for multiple modes of transportation and each freight service provider can have a different number of mode options. In addition, we consider a mode in a general way in that it can correspond to intermodal transportation. The former studied a network economic game theory model of a service-oriented Internet with choices and quality competition. For background on freight transportation modeling, we refer the reader to the books by Tavasszy and De Jong (2013), Ben-Akiva et al. (2013) and the references therein.

The new static and dynamic models in this paper also build on the work of Nagurney et al. (2002a), which introduced supply chain network equilibrium models but here the competition is in price and quality and not in quantities. See, also, the dynamic multilevel financial/informational/logistical framework of Nagurney et al. (2002b), the supernetwork model with freight carriers in Yamada et al. (2011), and the maritime chain model with carriers, ports and shippers of Talley and Ng (2013). For a plethora of supply chain network equilibrium models, along with the underlying dynamics, see the book by Nagurney (2006). For an overview of projected dynamical systems, which is the methodology that we utilize to describe the underlying competitive dynamics and the evolution of prices and quality, see Nagurney and Zhang (1996). However, none of the above multitiered competitive supply chain network equilibrium models with freight service provider behavior captured quality in transportation as well as in production. An extensive review of the overall supply chain network design literature has been provided by Farahani et al. (2014). Our framework is not in the context of supply chain network design; for an extensive review of the overall supply chain network design literature, see Farahani et al. (2014).

Our contributions to the existing literature are:

- We model explicit competition among manufacturing firms and freight service providers (carriers) in terms of prices and quality of the products that the firms offer and the prices and quality of the freight services provided. This multi-faceted inclusion of competition from price and quality dimensions leads to results that not just quantify quality at the product and service ends, but also helps to assess the trade-offs between quality and costs at each echelon of the supply chain that ultimately influences the demand. A model that considers oligopolistic competition among manufacturers and freight service providers under price and quality with multiple modes of transportation and non-separable, nonlinear, and asymmetric demand and cost functions is constructed for the first time with this paper.