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Supply chain network competition in time-sensitive markets

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ABSTRACT

We develop a game theory model for supply chain network competition in time-sensitive markets in which consumers respond to the average delivery time associated with the various firms' products. The firms' behavior is captured, along with the supply chain network topologies, with the governing equilibrium concept being that of Nash equilibrium. We derive the variational inequality formulation of the equilibrium conditions and provide illustrative examples. We also identify special cases for distinct applications. An algorithm is proposed, and the framework further illustrated through a case study in which we explore varying sensitivities to the average time delivery with interesting results.

1. Introduction

Timely deliveries of products are essential not only to consumers but to a company's reputation and bottom line. If products are not delivered in a timely manner, as illustrated by the December 2013 holiday season shipping fiasco in the United States, the unfulfilled demands may result in a tremendous loss of good will, anger, frustration, economic losses due to perished and spoiled products, and the potential loss of future business (cf. Ng and Stevens, 2014). A similar example from Sweden was when Christmas trees were home-delivered three days after Christmas due to shipping problems (Ullgren, 1999). Logistics providers commonly face delivery delays. For example, a large freight train operator reports that 5% of its trains are more than 1 h delayed (GreenCargo, 2014), causing many concerns in the industry about unreliable transport and forcing customers to make costly contingency plans. At the same time, reliability is ranked as one of the most important factors when selecting transport solutions (cf. Laitila and Westin, 2000; Maier et al., 2002; Vannieuwenhuyse et al., 2003; Danielis et al., 2005; Floden et al., 2010).

Hence, in supply chain management, the average time from the placement of an order to a product's delivery has emerged as a key performance indicator (KPI), signifying how effective and efficient a supply chain network is and providing a valuable metric as to the time a product spends in the system. As noted in Ketchen et al. (2008), in the 1990s, the average time to

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fulfill customer orders was measured in weeks, while today, delivery times are being measured in days, or, in some cases, in hours.

In the past decade, in order to increase responsiveness, and to enable comparisons across supply chains, Intel introduced the average delivery time, the Order Fulfillment Lead Time (OFLT), as a KPI (see Hensley et al., 2012). In military and defense, the Logistics Management Institute (cf. Klapper et al., 1999) refers to this KPI as the Logistics Response Time (LRT), measured, typically, in days. This supply chain performance measure is one of the four that has been utilized by the U.S. Department of Defense. Moreover, the average time for delivery of critical needs supplies, such as water, food, medicines, and even shelter, in disasters, is also an important performance measure for humanitarian relief chains (cf. Beamon, 2008; see also Sheu, 2007; Nagurney et al., 2014). Finally, for pharmaceuticals, more responsive time-efficient supply chains can save lives. As noted in Darabi (2013), the Kenya pharma supply chain improved the average time for sea and air shipments to clear customs from 21.8 days to 5.7 days, and from 2.5 days to 1.8 days, respectively, resulting in more timely deliveries of HIV/AIDS drugs to Kenyans. However, much work still remains globally. The World Bank Logistics Performance Index shows that the median import lead time is more than 3.5 times longer in low performing countries than in high performing countries (Arvis et al., 2012).

Because of the recognized competitive advantages associated with speed and timely deliveries (Boyaci and Ray, 2003, 2006), firms are increasingly differentiating their products to include time for delivery and consumers are responding. Online retailers, such as Amazon, have fulfillment/delivery options that often trade-off cost and speed of delivery although it can be noted that customers are not universally willing to pay much extra for faster deliveries (Lukic et al., 2013), which puts high demands on the supply chain design. Package delivery services, such as the U.S. Post Office, UPS, FEDEX, and DHL, routinely offer multiple delivery options with reduced delivery time coming at increased shipping cost. Similar development has long existed in passenger transport, where, for example, both regular and high speed rail services are offered to the same destinations but at different prices.

Recognition of the criticality of timely deliveries has given rise to increased attention to time-based competition from both practitioners and academics (cf. Stalk, 1988; Stalk and Hout, 1990; Blackburn et al., 1992; Hum and Sim, 1996; So and Song, 1998; Blackburn, 2012; Nagurney and Yu, 2014). In addition, time-based competition is also relevant to services (So, 2000) including services associated with information and data, such as online content distribution, online commerce, web hosting, etc.

Markets in which consumers are willing to pay a higher price for lower delivery times are referred to as being *time-sensitive*. In the case of perishable products, such as fresh produce, lower average delivery times often correspond to higher product quality (Yu and Nagurney, 2013). The same holds true for certain pharmaceuticals and blood, whose quality may deteriorate with age (see, e.g., Nagurney et al., 2013). Companies will often make a trade-off between transport time and other characteristics when designing their supply chains. For example, Evans and Harrigan (2005) showed that the U.S. apparel industry adapts to the increasingly rapid fashion changes by moving production where timeliness is important from lower wage locations in Asia to higher wage locations in Mexico and the Caribbean that are closer to the U.S. consumer, thus trading cost for time. Another well-known example is Benetton that uses a postponement strategy by delaying the dying of garments during production to be able to respond faster to trends (Dapiran, 1992). A recent vivid example is the demand for apparel and related products based on the top-grossing Disney animated film *Frozen*, with shipments from manufacturing plants in China increasingly being airlifted because of the demand and willingness of consumers to pay higher prices (see Palmeri, 2014).

Interestingly, for data and information services in isolated, rural, and/or developing parts of the globe, models of delay tolerant networks have been constructed in which both communication and transportation are used for delivery (see Pentland et al., 2004; Marentes et al., 2014). Transportation, in the form of buses, motorcycles, and bicycles, is often used for the mechanical backhaul of the information delivery media. In such delay tolerant networks, where cost and infrastructure play important roles, pricing is also done in accordance with the average time of delivery (see Marentes et al., 2014). Furthermore, time-based competition is expected to play an important role in future Internet architectures (see, e.g., Rouskas et al., 2013) in which consumers may be willing to pay higher prices for quicker content deliveries.

Today's supply chains span the globe, which may entail production on one or more continents, transportation over land and sea, storage at multiple locations, and distribution to geographically dispersed demand markets. Large demands at a demand market may be supplied by a firm that has multiple manufacturing plants, multiple distribution centers, and uses multiple modes of transportation. Hence, different pathways in a firm's supply chain network may have been utilized to provide consumers with the product and each of these pathways may have an associated different time. Competition today takes place between supply chains and not individual companies (cf. Zhang, 2006; Christopher, 2011) with the end customer basing his preference on the product delivered and its associated characteristics, such as delivery time. However, given today's complex supply chain network topologies, consumers may not always be aware of the precise manufacturing plant, distribution center, and mode of transport between the two, that were used for a product; nor may they know of the time associated with supply chain network activities such as manufacturing, storage, and distribution. Hence, there may exist information asymmetry. Nevertheless, consumers at demand markets are aware of the average time for the delivery of the ordered products, and respond accordingly through the prices that they are willing to pay. Although there has been work done on information asymmetry in product quality dating to the work of the Nobel laureate Akerlof (1970) (see, also, Spence, 1975; Stiglitz, 1987; Nagurney and Li, 2014, and the references therein) information asymmetry in terms of time has not been explored rigorously in a supply chain network context.