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# Sustainable fashion supply chain management under oligopolistic competition and brand differentiation

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ABSTRACT

In this paper, we developed a new model of oligopolistic competition for fashion supply chains in the case of differentiated products with the inclusion of environmental concerns. The model assumes that each fashion firm's product is distinct by brand and the firms compete until an equilibrium is achieved. Each fashion firm seeks to maximize its profits as well as to minimize its emissions throughout its supply chain with the latter criterion being weighted in an individual manner by each firm. The competitive supply chain model is network-based and variational inequality theory is utilized for the formulation of the governing Nash equilibrium as well as for the solution of the case study examples. The numerical examples illustrate both the generality of the modeling framework as well as how the model and computational scheme can be used in practice to explore the effects of changes in the demand functions; in the total cost and total emission functions, as well as in the weights.



## 1. Introduction

The fashion and apparel industry faces vast challenges as well as opportunities in the reduction of its environmental impact globally. The demand for apparel that is produced and distributed in a manner that minimizes the use (and discarding) of toxic dyes, raw materials such as cotton grown with pesticides, as well as the generation of waste in terms of textiles and byproducts (including packaging) is coming not only from consumers but also, more recently, even from firms such as Levi's, Gap, H&M, and Wal-Mart that wish to enhance or to maintain a positive brand identity (see, e.g., Claudio, 2007; Glausiusz, 2008; Rosenbloom, 2010; Tucker, 2010).

In addition, organizations such as the Natural Resources Defense Council (NRDC) are now increasingly emphasizing that this industry's reduction of its environmental impacts will require that brands and retailers reexamine their supply chains way back to the inputs into their production processes and take more responsibility even for the fabric utilized (cf. Tucker, 2010).

In order to fix ideas, and to emphasize the scope of the environmental issues associated with the fashion and apparel industry, we now provide some data. According to Claudio (2007), polyester is a man-made fiber whose demand from the fashion industry has doubled in the past 15 years. Its manufacture requires petroleum and releases such emissions as volatile organic compounds and gases such as hydrogen chloride, as well as particulates. Other byproducts associated with its production are emitted in the waste water. However, even natural fibers used in textiles for apparel may also leave a large environmental imprint. For example, the production of cotton, one of the most versatile fibers used in clothing, accounts for a quarter of all the pesticides used in the United States, which is the largest exporter of cotton in the world (see Claudio, 2007). According to the NRDC (see Tucker, 2010), textile manufacturing pollutes as much as 200 tons of water per ton of fabric. In China, for example, a textile factory may also burn about 7 tons of carbon emitting coal per ton of fabric produced. In the case of blue jean production, Xintang, located in the northeastern part of the Pearl River Delta in China, is where approximately 200 million pairs of jeans are produced annually for 1000 different labels. The standard jean dyeing process dispenses into its waste water a mixture of dye, bleach, and detergent and, as a consequence, the production of blue jeans in such a manner is partly to blame for the pollution of the Pearl River (see UPI.com, 2010).

As the production of apparel has become global and competition has intensified (see Gereffi and Memedovic, 2003), with an increased prominence of brands and buyer-driven value chains, new networks are transforming this industry. Interestingly, whereas in 1992 about 49% of all retail apparel sold in the United States was actually made there, by 1999 the proportion had fallen

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to just 12% (Rabon, 2001). Between 1990 and 2000, the value of apparel imports to the US increased from $25 billion to $64 billion. According to Gereffi and Memedovic (2003), the top exporters of apparel in 2000, with a value of over $1 billion in US dollars, were: China, Hong Kong (now referred to as Hong Kong SAR), the United States, Mexico, and Turkey, whereas in 1980, the major exporters were: Hong Kong SAR, South Korea, Taiwan, China, and the United States. However, as noted in Nagurney and Woolley (2010), with the growing investment and industrialization in developing nations, it is also important to evaluate the overall impact at not only the operational level, but also in terms of the environment. For example, between 1988 and 1995, multinational corporations invested nearly $422 billion worth in new factories, supplies, and equipment in developing countries (World Resources Institute, 1998). Through globalization, firms of industrialized nations may make use of manufacturing plants in developing nations that offer lower production costs; however, more than not, combined with inferior environmental concerns, due, for example, to a looser environmental regulatory system and/or lower environmental impact awareness.

Also, it is imperative to recognize that the accounting of environmental emissions associated with the fashion and apparel industry, especially given its global dimensions in terms of both manufacturing plant locations and demand markets, include emissions generated in the transportation and distribution of the products across oceans and vast tracts of land. For example, H&M, a well-known fast fashion company, is cognizant of the environmental impact of even the fuels used in the transportation of its fashion products as well as the number of shipments needed for distribution. According to the Guardian (2010), H&M has identified that 51% of its carbon imprint in 2009 was due to transportation. In order to reduce the associated emissions, it began more direct shipments that avoided intermediate warehouses, decreased the volumes shipped by ocean and air by 40% and increased the volume of products shipped by rail, resulting in an over 700 ton decrease in the amount of carbon dioxide emitted.

In this paper, we develop an oligopoly model for fashion supply chain competition which explicitly considers different brands and different degrees of environmental consciousness and sustainability. The network-based model, which is formulated and studied as a variational inequality problem, captures competition among the firms in manufacturing, transportation/distribution, and storage, and assumes that the firms seek not only to maximize their profits but also care, in an individual way, about the emissions that they generate. The supply chain network oligopoly model that we develop is novel, and fills major research gaps, by contributing to understanding in several dimensions: (1) it handles product differentiation through branding; (2) it explicitly allows for alternative modes of transportation for product distribution as well as the possibility of an option of direct shipment from manufacturing plants, and (3) it enables each fashion/apparel producing firm to individually determine, by use of its individual concern through a weighting factor, its environmental impacts through the emissions that it generates not only in the manufacture of its product but also throughout its supply chain, with the ultimate deliveries at the demand markets.

We now discuss some of the related literature. Nagurney and Woolley (2010) also developed multicriteria supply chain network models for sustainability but focused on cost-minimization and system-optimization, as opposed to profit maximization, and oligopolistic competition, as we do in this paper. They identified a synergy measure to evaluate potential cost and environmental synergies associated with firms that are involved in mergers and/or acquisitions. More recently, Nagurney and Nagurney (2010) proposed a multicriteria network design model for the sustainable engineering of supply chains that also focused on optimization and not on oligopolistic competition with profit maximization. Nagurney (2010a), on the other hand, developed a supply chain network design model in the case of oligopolistic competition but did not include environmental issues. Moreover, in the latter model it was assumed that the product that was being produced by multiple competing firms was homogeneous. In the fashion/apparel industry, on the other hand, brands are distinct and consumers who purchase apparel and fashion products may be brand-sensitive due to status appeal, reputation, environmental awareness, etc. Hence, the model in this paper considers the fashion or apparel product manufactured by a given firm to be differentiated by brand from similar products produced by the other firms that it competes with. Our supply chain network oligopoly model is new from this perspective and also due to the inclusion of environmental emissions within a multicriteria, competitive decision-making framework.

Nagurney and Yu (2011) focused on multicriteria decision-making for fashion supply chain management with the minimization of cost (see also Nagurney, 2010b) and the minimization of time as relevant criteria and assumed that the demand for the fashion product was known at each demand market. The model in this paper, in contrast, assumes that the demand for the particular brand is elastic and not fixed and considers multiple, competing firms rather than a single firm. For an edited volume on fashion supply chain management, a relatively new area of application of rigorous tools, see Choi (2011), the focused journal special issue edited by Choi and Chen (2008), and the papers by Sen (2008) and Brun et al. (2008).

Hence, this paper builds on the existing literature in sustainable supply chain management, with a focus on system-wide issues and in an industry in which competition and brands are the reality. Indeed, as early as Beamon (1999), Sarkis (2003), Corbett and Kleindorfer (2003), Nagurney and Toyasaki (2003, 2005), Sheu et al. (2005), Kleindorfer et al. (2005), Nagurney et al. (2007) and Linton et al. (2007) it has been argued that sustainable supply chains are critical for the examination of operations and the environment, with sustainable fashion being a more recent topic in both research and practice (see e.g., de Brito et al., 2008 and the references therein). Sustainable supply chains have arisen as a focus for special issues (see Piplani et al., 2008) and have advanced to a degree that even policies to reduce emissions have been explored in rigorous frameworks (see Wu et al., 2006; Nagurney et al., 2006; Chaabane et al., in press). For a thorough survey of sustainable supply chain management until 2008, see Seuring and Muller (2008). Nevertheless, a general, rigorous modeling and computational framework that captures oligopolistic competition, brand differentiation, and environmental concerns, in a supply chain network setting has not, heretofore, been constructed.

This paper is organized as follows. In Section 2, we develop the new sustainable fashion supply chain network oligopoly model with brand differentiation and provide some qualitative properties. In Section 3.1, we present the computational procedure which we then apply in Section 4 to compute solutions to a spectrum of numerical examples that comprise our case study. The case study illustrates both the generality of our framework and its applicability. We also provide managerial insights based on our computational case study. In Section 5, we summarize our findings, discuss the many directions that future research can take, and present our conclusions.

## 2. The sustainable fashion supply chain network oligopoly model

We consider a finite number of $I$ fashion firms, with a typical firm denoted by $i$, who are involved in the production, storage,