Sustainable Fashion Supply Chain Management Under Oligopolistic Competition and Brand Differentiation

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Outline

- Background and Motivation
- An Overview of the Relevant Literature
- The Sustainable Fashion Supply Chain Network Oligopoly Model
- The Algorithm
- Case Study with Managerial Insights
- Summary and Conclusions

Background and Motivation

The fashion and apparel industry is facing vast challenges in terms of the environmental impacts.

Background and Motivation

- According to the Natural Resources Defense Council (NRDC), textile manufacturing pollutes as much as 200 tons of water per ton of fabric.
- In China, a textile factory may also burn about 7 tons of carbon emitting coal per ton of fabric produced (see Tucker (2010)).
- 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 emissions into the air and the water (see Claudio (2007)).
- The production of cotton 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)).

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Background and Motivation

In the last three decades, there has been a migration of clothing manufacturers from developed to developing countries.

- Whereas in 1992 about 49% of all retail apparel sold in the United States was actually made there, by 1999 the proportion had fallen to just 12% (Rabon (2001)).
- Between 1990 and 2000, the value of apparel imports to the US increased from $25 billion to $64 billion.

Lower production cost is not the only reason for the globalization of apparel manufacturing. Some firms may be taking advantage of a looser environmental regulatory system and/or lower environmental impact awareness in developing nations (see Allwood et al. (2006)).

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Xintang, the 'Jeans Capital' of the World

Background and Motivation

Given its global dimensions, it is crucial to realize the seriousness of emissions generated along the entire supply chains associated with the fashion and apparel industry, include emissions generated in the transportation and distribution of the products across oceans and vast tracts of land.

The demand to minimize the environmental pollution is coming not only from consumers but, more recently, even from fashion firms that wish to enhance or to maintain a positive brand identity (see, e.g., Claudio (2007), Glausiusz (2008), Rosenbloom (2010), Tucker (2010), and Zeller Jr. (2011)).

Background and Motivation

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 (H&M (2010)).

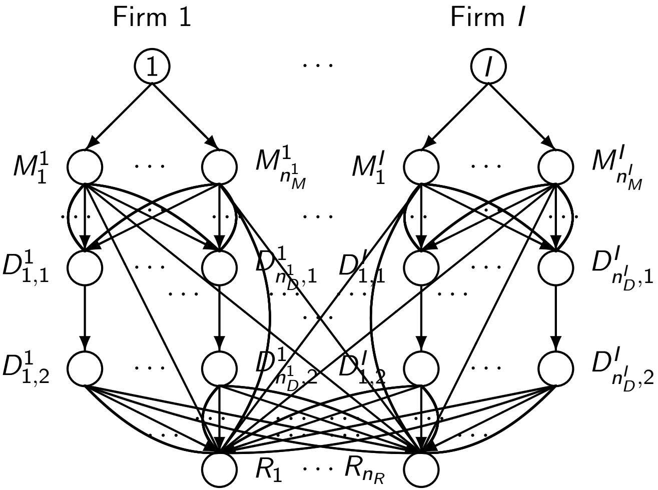
Relevant Literature

- Sustainable Supply Chains
  - Yeung et al. (2008) claimed that social compliance is one of the influentials of operational performance in the clothing manufacturing industry, especially for imported fashion products.
  - Beamon (1999), Sarkis (2003), Corbett and Kleindorfer (2003), Nagurney and Toyasaki (2003, 2005), Sheu, Chou, and Hu (2005), Kleindorfer, Singhal, and van Wassenhove (2005), Nagurney, Liu, and Woolley (2007), Linton, Klassen, and Jayaraman (2007), Piplani, Pujawan, and Ray (2008), Nagurney and Nagurney (2010), and Nagurney and Woolley (2010)
  - Wu et al. (2006), Nagurney, Liu, and Woolley (2006), and Chaabane, Ramudhin, and Paquet (2010)

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, and distribution of a fashion product and who compete noncooperatively in an oligopolistic manner. Each firm corresponds to an individual brand representing the product that it produces.

The Fashion Supply Chain Network Topology of the Oligopoly



Demands, Path Flows, and Link Flows

Let d_{ik} denote the demand for fashion firm i's product at demand market k. The products of all these fashion firms are not homogeneous but are differentiated by *brand*.

Let x_p denote the nonnegative flow on path p joining (origin) node i; $i = 1, \ldots, I$ with a (destination) demand market node. Let f_a denote the flow on link a.

The Conservation of Flow Equations

$$\sum_{p \in P_k^i} x_p = d_{ik}, \quad k = 1, \ldots, n_R; \; i = 1, \ldots, I. \tag{1}$$

$$f_a = \sum_{p \in P} x_p \delta_{ap}, \quad \forall a \in L. \tag{2}$$

The demand price of fashion firm i's product at demand market R_k is denoted by ρ_{ik} and the demand price functions are assumed to be continuous, continuously differentiable and monotone decreasing.

$$\rho_{ik} = \rho_{ik}(d), \quad k = 1, \ldots, n_R; \; i = 1, \ldots, I. \tag{3}$$

The total operational cost on a link is assumed to be a function of the product flows on all the links, that is,

$$\hat{c}_a = \hat{c}_a(f), \quad \forall a \in L. \tag{4}$$

The total cost on each link is assumed to be convex and is continuously differentiable.

The profit function π_i of firm i; $i = 1, \ldots, I$, is:

$$\pi_i = \sum_{k=1}^{n_R} \rho_{ik}(d) \sum_{p \in P_k^i} x_p - \sum_{a \in L^i} \hat{c}_a(f). \tag{5}$$

The emission-generation function associated with link a, denoted by $\hat{e}_a$, is assumed to be a function of the product flow on that link, that is,

$$\hat{e}_a = \hat{e}_a(f_a), \quad \forall a \in L. \tag{6}$$

These functions are assumed to be convex and continuously differentiable.

Each fashion firm aims to minimize the total amount of emissions generated in the manufacture, storage, and shipment of its product.

$$\text{Minimize} \quad \sum_{a \in L^i} \hat{e}_a(f_a). \tag{7}$$

The Sustainable Fashion Supply Chain Network Oligopoly Model

The multicriteria decision-making problem faced by fashion firm i; $i = 1, \ldots, I$, is:

$$U_i = \sum_{k=1}^{n_R} \rho_{ik}(d) \sum_{p \in P_k^i} x_p - \sum_{a \in L^i} \hat{c}_a(f) - \omega_i \sum_{a \in L^i} \hat{e}_a(f_a), \qquad (8)$$

where the term ω_i is assumed to be the price that firm i would be willing to pay for each unit of emission on each of its links, representing the environmental concern of firm i.

In view of (1)-(8),

$$U = U(X), \qquad (9)$$

where U is the I-dimensional vector of all the firms' utilities.

Definition: Supply Chain Network Cournot-Nash Equilibrium

A path flow pattern $X^* \in K = \prod_{i=1}^{I} K_i$ *is said to constitute a supply chain network Cournot-Nash equilibrium if for each firm* i; $i = 1, \ldots, I$:

$$U_i(X_i^*, \hat{X}_i^*) \geq U_i(X_i, \hat{X}_i^*), \quad \forall X_i \in K_i, \tag{10}$$

where
$\hat{X}_i^* \equiv (X_1^*, \ldots, X_{i-1}^*, X_{i+1}^*, \ldots, X_I^*)$ *and* $K_i \equiv \{X_i | X_i \in R_+^{n_{P^i}}\}$.

Theorem: Variational Inequality Formulation

Assume that for each fashion firm i; $i = 1, \ldots, I$, the utility function $U_i(X)$ is concave with respect to the variables in X_i, and is continuously differentiable. Then $X^* \in K$ is a sustainable fashion supply chain network Cournot-Nash equilibrium if and only if it satisfies the variational inequality:

$$-\sum_{i=1}^{I} \langle \nabla_{X_i} U_i(X^*)^T, X_i - X_i^* \rangle \geq 0, \quad \forall X \in K, \tag{11}$$

where $\langle \cdot, \cdot \rangle$ denotes the inner product in the corresponding Euclidean space and $\nabla_{X_i} U_i(X)$ denotes the gradient of $U_i(X)$ with respect to X_i.

Variational Inequality Formulation in Path Flows

The solution of variational inequality (11) is equivalent to the solution of the variational inequality: determine $x^* \in K^1$ *satisfying:*

$$\sum_{i=1}^{I} \sum_{k=1}^{n_R} \sum_{p \in P_k^i} \left[\frac{\partial \hat{C}_p(x^*)}{\partial x_p} + \omega_i \frac{\partial \hat{E}_p(x^*)}{\partial x_p} - \rho_{ik}(x^*) - \sum_{l=1}^{n_R} \frac{\partial \rho_{il}(x^*)}{\partial d_{ik}} \sum_{p \in P_l^i} x_p^* \right]$$

$$\times [x_p - x_p^*] \geq 0, \ \forall x \in K^1, \qquad (12)$$

where $K^1 \equiv \{x | x \in R_+^{n_P}\}$, $\frac{\partial \hat{C}_p(x)}{\partial x_p} \equiv \sum_{b \in L^i} \sum_{a \in L^i} \frac{\partial \hat{c}_b(f)}{\partial f_a} \delta_{ap}$ *and* $\frac{\partial \hat{E}_p(x)}{\partial x_p} \equiv \sum_{a \in L^i} \frac{\partial \hat{e}_a(f_a)}{\partial f_a} \delta_{ap}$.

Variational Inequality Formulation in Link Flows

In addition, (12) can be re-expressed in terms of link flows as: determine the vector of equilibrium link flows and the vector of equilibrium demands $(f^*, d^*) \in K^2$, such that:

$$\sum_{i=1}^{I} \sum_{a \in L^i} \left[\sum_{b \in L^i} \frac{\partial \hat{c}_b(f^*)}{\partial f_a} + \omega_i \frac{\partial \hat{e}_a(f_a^*)}{\partial f_a} \right] \times [f_a - f_a^*]$$

$$+ \sum_{i=1}^{I} \sum_{k=1}^{n_R} \left[-\rho_{ik}(d^*) - \sum_{l=1}^{n_R} \frac{\partial \rho_{il}(d^*)}{\partial d_{ik}} d_{il}^* \right] \times [d_{ik} - d_{ik}^*] \geq 0, \quad \forall (f, d) \in K^2, \tag{13}$$

where $K^2 \equiv \{(f, d) | \exists x \geq 0, \text{ and } (1) \text{ and } (2) \text{ hold}\}$.

Theorem: Existence

There exists at least one Nash Equilibrium, equivalently, at least one solution to variational inequality (12) (equivalently, (13)), since in the light of the demand price functions (3), there exists a $b > 0$*, such that variational inequality*

$$\langle F(X^b)^T, X - X^b \rangle \geq 0, \quad \forall X \in \mathcal{K}_b, \tag{14}$$

admits a solution in $\mathcal{K}_b \equiv \{x | 0 \leq x \leq b\}$ *with*

$$x^b \leq b. \tag{15}$$

Theorem: Uniqueness

Variational inequality (13) admits at least one solution. Moreover, if the function $F(X)$ of variational inequality (13), is strictly monotone on $\mathcal{K} \equiv K^2$, that is,

$$\langle (F(X^1) - F(X^2))^T, X^1 - X^2 \rangle > 0, \quad \forall X^1, X^2 \in \mathcal{K}, \; X^1 \neq X^2. \tag{16}$$

then the solution to variational inequality (13) is unique, that is, the equilibrium link flow pattern and the equilibrium demand pattern are unique.

The Algorithm – The Euler Method

At an iteration τ of the Euler method (see Dupuis and Nagurney (1993) and Nagurney and Zhang (1996)) one computes:

$$X^{\tau+1} = P_{\mathcal{K}}(X^{\tau} - a_{\tau}F(X^{\tau})), \tag{17}$$

where $P_{\mathcal{K}}$ is the projection on the feasible set $\mathcal{K}$ and F is the function that enters the variational inequality problem: determine $X^* \in \mathcal{K}$ such that

$$\langle F(X^*)^T, X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K}, \tag{18}$$

where $\langle \cdot, \cdot \rangle$ is the inner product in n-dimensional Euclidean space, $X \in R^n$, and $F(X)$ is an n-dimensional function from $\mathcal{K}$ to R^n, with $F(X)$ being continuous.

The sequence $\{a_{\tau}\}$ must satisfy: $\sum_{\tau=0}^{\infty} a_{\tau} = \infty$, $a_{\tau} > 0$, $a_{\tau} \to 0$, as $\tau \to \infty$.

Explicit Formulae for the Euler Method Applied to the Sustainable Fashion Supply Chain Network Oligopoly Variational Inequality (12)

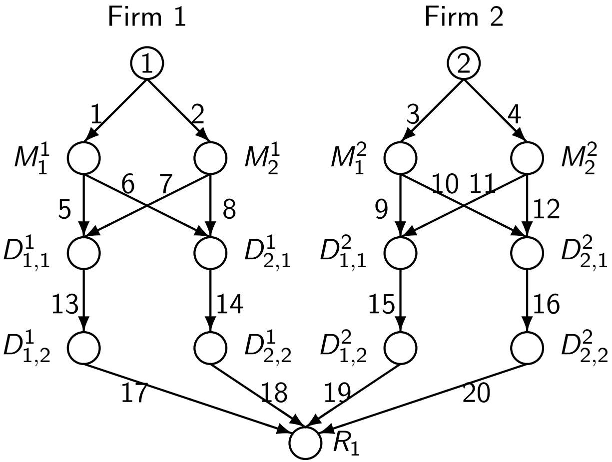
$$x_p^{\tau+1} = \max\{0, x_p^\tau + a_\tau(\rho_{ik}(x^\tau) + \sum_{l=1}^{n_R} \frac{\partial \rho_{il}(x^\tau)}{\partial d_{ik}} \sum_{p \in P_l^i} x_p^\tau$$

$$-\frac{\partial \hat{C}_p(x^\tau)}{\partial x_p} - \omega_i \frac{\partial \hat{E}_p(x^\tau)}{\partial x_p})\}, \quad \forall p \in P_k^i, \forall k, \forall i. \qquad (19)$$

Case Study

There are two fashion firms, Firm 1 and Firm 2, each of which is involved in the production, storage, and distribution of a single fashion product, which is differentiated by its brand. Each firm has, at its disposal, two manufacturing plants, two distribution centers, and serves a single demand market. The manufacturing plants M_1^1 and M_1^2 are located in the United States, whereas the manufacturing plants M_2^1 and M_2^2 are located off-shore with lower operational costs. However, the demand market is in the United States as are the distribution centers.

The Fashion Supply Chain Network Topology for the Case Study



Problem Set 1

Fashion Firm 1 cares about the emissions that it generates much more than Firm 2 does, which is indicated by the respective values of ω_1 and ω_2, where $\omega_1 = 5$ and $\omega_2 = 1$. In addition, Firm 1 utilizes more advanced technologies in its supply chain activities in order to lower the emissions that it generates, but at relatively higher costs.

Example 1

$$\rho_{11}(d) = -d_{11} - .2d_{21} + 300, \quad \rho_{21}(d) = -2d_{21} - .5d_{11} + 300.$$

Example 2

$$\rho_{21}(d) = -3d_{21} - .5d_{11} + 300.$$

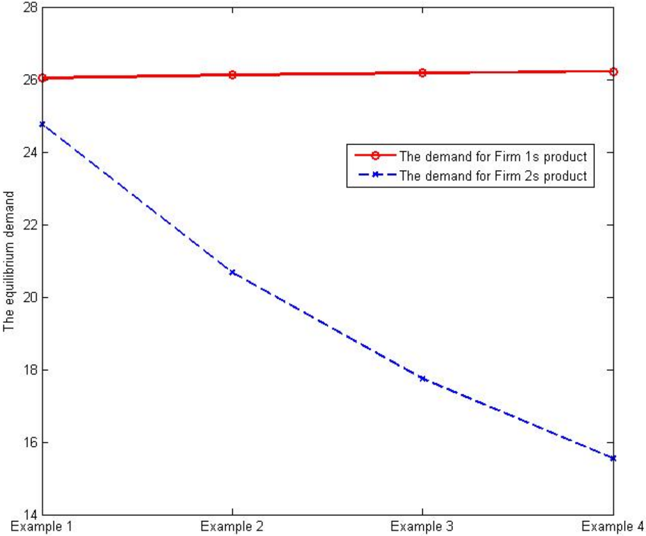
Example 3

$$\rho_{21}(d) = -4d_{21} - .5d_{11} + 300.$$

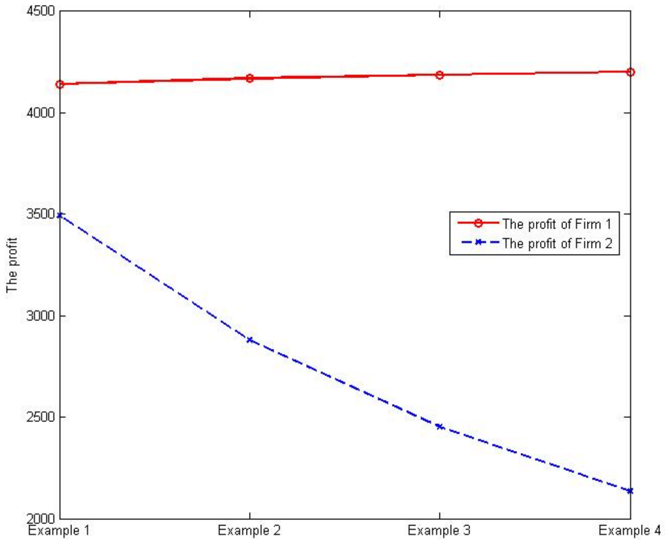
Example 4

$$\rho_{21}(d) = -5d_{21} - .5d_{11} + 300.$$

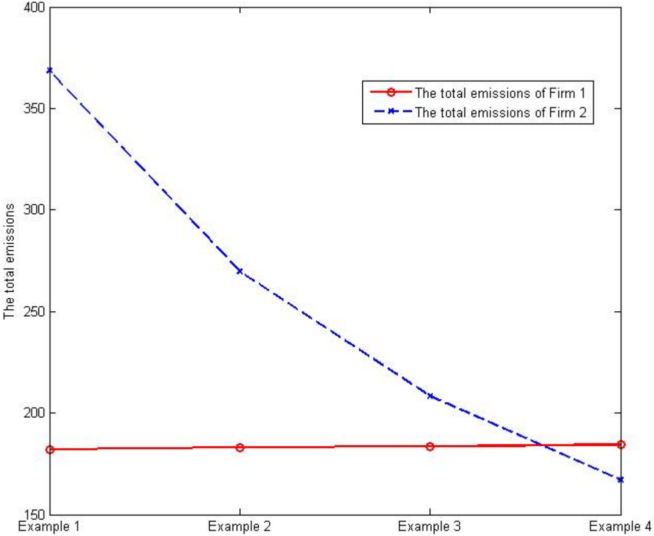
The Equilibrium Demands as ρ_{21} Varies



The Equilibrium Profits as ρ_{21} Varies



The Equilibrium Total Emissions as ρ_{21} Varies

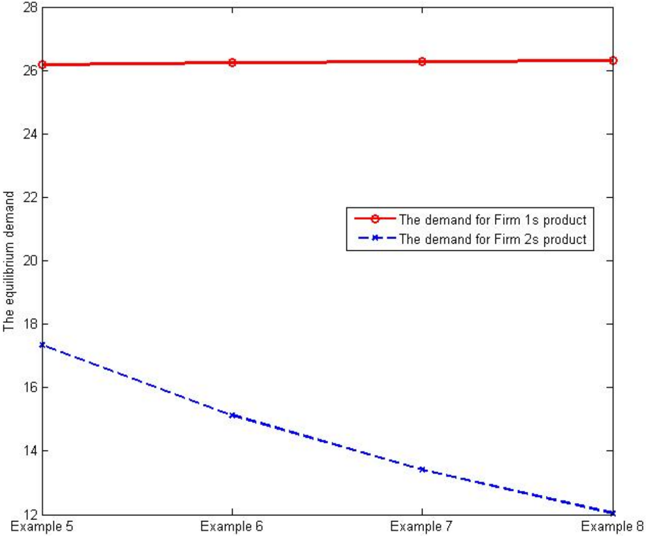


Problem Set 2

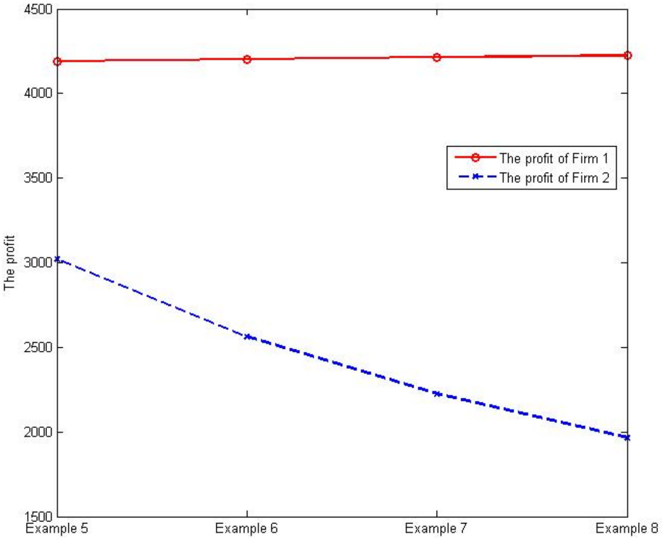
Firm 2 was now more environmentally conscious and raised ω_2 from 1 to 5. Hence, in this set of examples, Firm 1 and Firm 2 both had their ω weights equal to 5. Examples 5 through 8 had their data identical to the data in Examples 1 through 4, respectively, except for the larger value of ω_2.

The weights, the ω_is, may also be interpreted as *taxes* in that a governmental authority may impose a tax associated with carbon emissions, for example, that each firm must pay.

The Equilibrium Demands as ρ_{21} Varies



The Equilibrium Profits as ρ_{21} Varies



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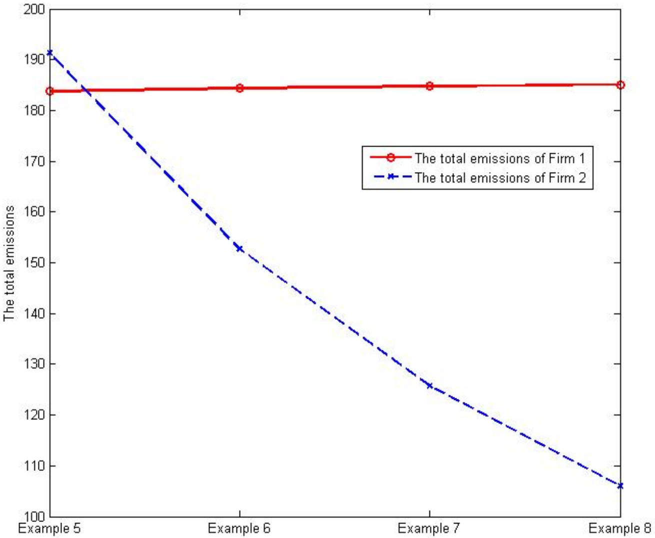


Problem Set 3

Example 9

$$\hat{c}_3(f) = 10f_3^2 + 10f_3, \quad \hat{c}_4(f) = f_4^2 + 7f_4,$$

$$\hat{e}_3(f_3) = .05f_3^2 + .5f_3, \quad \hat{e}_4(f_4) = .1f_4^2 + .8f_4.$$

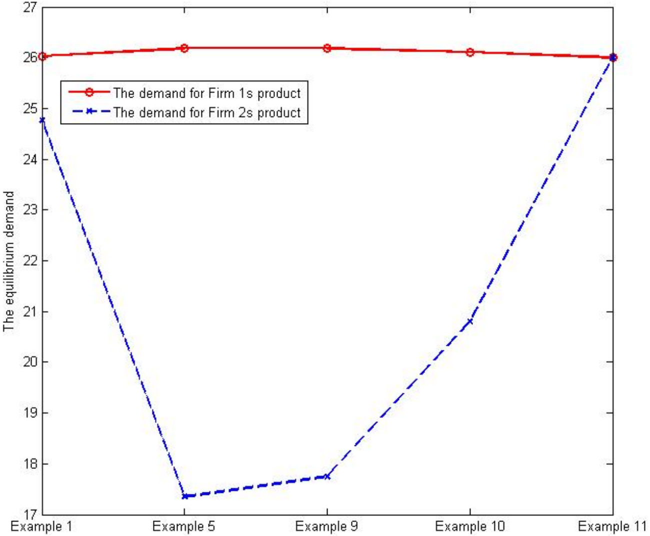
Example 10

Fashion Firm 2 made even a greater effort to lower its emissions, not only focusing on its manufacturing processes, but also on all other supply chain activities.

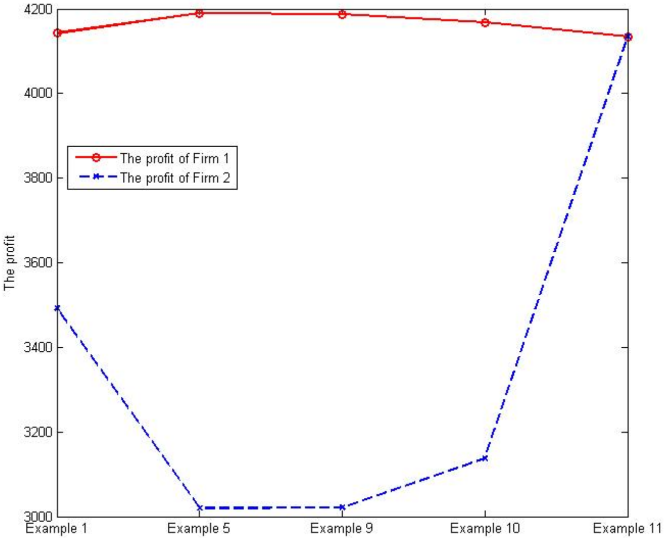
Example 11

Firm 1 and 2 were *identical*.

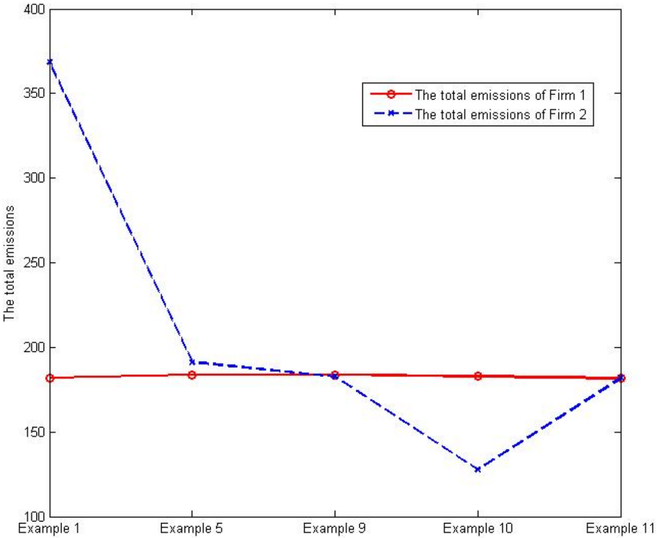
Comparison of the Equilibrium Demands



Comparison of the Equilibrium Profits



Comparison of the Equilibrium Total Emissions



Case Study

- Consumers' environmental consciousness can be a valuable incentive to spur fashion companies to reexamine their supply chains so as to reduce their environmental pollution, which can, in turn, help such companies to obtain competitive advantages and increased profits.
- The development of a positive image for a firm in terms of its environmental consciousness and concern may also be an effective marketing strategy for fashion firms.

Summary and Conclusions

- We developed a competitive supply chain network model, using variational inequality theory, that captures oligopolistic competition with fashion product brand differentiation.
  - The model captures competition through brand differentiation.
  - The model allows for each firm to individually weight its concern for the environment.
  - Alternatives such as multiple modes of transportation can be investigated.

Summary and Conclusions

- We presented a case study, to demonstrate the effects of changes in the demand price functions, the total cost and total emission functions, and the weights associated with the environmental criterion on the equilibrium product demands, the product prices, profits, and utilities.
  - The environmental weights could also be interpreted as taxes and, thus, in exploring different values an authority such as the government could assess a priori the effects on the firms' emissions and profits.
  - The case study also demonstrated that consumers can have a major impact, through their environmental consciousness, on the level of profits of firms in their favoring of firms that adopt environmental pollution-abatement technologies for their supply chain activities.

Thank You!

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