Fashion Supply Chain Network Competition with Ecolabelling

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INFORMS Annual Meeting, Philadelphia, PA
November 1-4, 2015

This talk is based on the paper:

Nagurney, A., Yu, M., Floden, J., 2015. Fashion supply chain network competition with ecolabelling. In **Sustainable Fashion Supply Chain Management: From Sourcing to Retailing**, T.-M. Choi and T.C.E. Cheng, Editors, Springer, pp 61-84.

where a full list of references can be found.

Acknowledgments

The research was supported, in part, by the School of Business, Economics and Law at the University of Gothenburg through its Visiting Professor Program.

This support is gratefully acknowledged.

Outline

- Background and Motivation
- An Overview of the Relevant Literature
- The Fashion Supply Chain Network Model with Ecolabelling
- An Illustrative Example and Variant
- The Algorithm
- Case Study
- Summary and Conclusions

Background and Motivation

- **Clothing and accessories** are the consumer goods that, next to food and beverages, are **purchased most often** and also **replaced most frequently**.

Background and Motivation

- **Apparel and fashion products**, along with **textiles**, represent an immense industry with wide economic importance valued at **$3 trillion** in U.S. dollars in terms of turnover in 2011.
- This industry utilizes extensive amounts of **natural resources** from water and grown cotton, **energy**, as well as **chemicals**.
- There will be **9 billion people** on our planet in 2050. Growth in this industry is expected, along with an expected increase in associated emissions, if appropriate environmental mitigation actions are not taken.

Cotton uses only **3% of the world farmlands** but more than **10% of the total pesticides** and about **25% of the world's insecticides**.

Background and Motivation

This industrial sector is a primary source of **GHG (greenhouse gas) emissions**.

- Apparel and textiles account for about **10%** of the total carbon emissions.

- Textiles are the **fifth largest contributor** to CO_2 emissions in the United States.

- **10%** of the total CO_2 emissions from a life cycle perspective can be attributed to transport.

Background and Motivation

- Fashion trends that once lasted for years are now replaced **several times per season**.
- The rapidly changing world of fashion pushes towards **overconsumption of resources**.

Background and Motivation

- The increasing competitive pressure on lower prices has led to production moving to **low cost** countries in the Far East with **less strict health and safety legislation**.
- Apparel and fashion products are manufactured, stored, and distributed in global supply chains.
  - Only **20%** of the United Kingdom's annual consumption of clothing is manufactured there.
- The long and fragmented fashion supply chain is characterized by **low transparency and control**.

Background and Motivation

- There is a divide between those who get the **benefits** from fashion on the customers' side and those who pay the **social and environmental costs**.

- A transformation of this industry should include **transparency**, as well as the "**optimization**" of **environmental footprints**.

- Preliminary efforts are underway with the establishment of the **Sustainable Apparel Coalition** (SAC) and its creation of the **Higg Index**.

Background and Motivation

- **Consumers** become increasingly aware of the negative environmental impacts of manufacturing apparel.
- Many **fashion firms** are recognizing that green or eco-friendly apparel is a way of differentiating one's products and enhancing brand recognition.
- However, eco-friendly clothes are bought only if customers perceive the products as **superior** to competitors' offerings.

Background and Motivation

- There are challenges:
  - **51%** of customers identify environmental friendliness as being an important factor in their apparel purchasing decisions.
  - Only **26%** are willing to pay more for such clothes.
- Consumers need a readily accessible and easily understandable mechanism to identify the environmental impact of the apparel that they purchase.
  - **83%** of customers believe that the company should be responsible in informing the customers about the manufacturing conditions; and
  - **95%** of customers prefer to get this information through product labelling.

- **Ecolabels** reveal the product carbon footprint to consumers.
- Such labels entail a **cost** to producers, but provide **valuable information** to concerned consumers.
- The **environmental quality** associated with an apparel or fashion product may be a positive attribute.

Relevant Literature

- Fashion Supply Chains:
  Choi (2011), Choi et al. (2013)

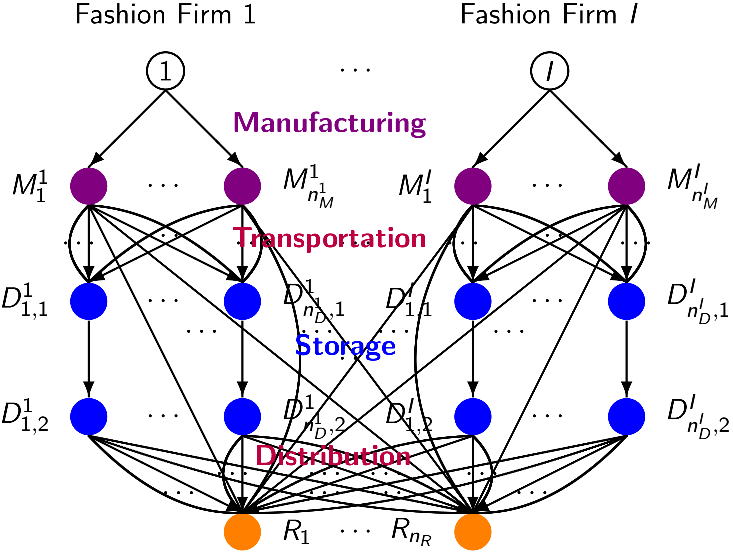
- Sustainable Supply Chains:
  Sheu, Chou, and Hu (2005), Seuring and Muller (2008), Nagurney and Nagurney (2011), Boone, Jayaraman, and Ganeshan (2012), Nagurney (2013), Nagurney, Yu, and Floden (2013)

- Network Economics:
  Nagurney and Yu (2011), Nagurney and Yu (2012), Nagurney, Li, and Nagurney (2013), Nagurney and Li (2014)

The Fashion Supply Chain Network Model with Ecolabelling

- The **profit-maximizing** fashion firms compete noncooperatively in an **oligopolistic** manner.
- The fashion firms incur **ecolabelling** costs.
- A fashion product is distinguished by the firm's **brand**.
  - Fast fashion products: H&M, Zara, etc.
  - Luxury brands: Chanel, Hermes, Vuitton, etc.

The Fashion Supply Chain Network Model with Ecolabelling



Conservation of Flow Equations

- f_a: the flow on **link** a;
- x_p: the flow on **path** p joining fashion firm i with a demand market node;
- d_{ik}: the **demand** for fashion firm i's product at demand market R_k.

Relationship between link flows and path flows

$$f_a = \sum_{p \in P} x_p \delta_{ap}, \quad \forall a \in L. \tag{1}$$

Relationship between path flows and demands

$$\sum_{p \in P^i_k} x_p = d_{ik}, \quad \forall i, \forall k. \tag{2}$$

Nonnegativity

$$x_p \geq 0, \quad \forall p \in P. \tag{3}$$

Operational Costs

- $e_a(f_a)$: the **carbon emissions** generated on link a:
  - It includes the emissions generated also through sourcing; and
  - It also includes other GHG emissions.

Total Operational Cost Functions

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

- The total cost expressions capture **supply-side competition** among the firms for resources used in the manufacture, transportation, storage, and distribution of their products.

Ecolabelling Costs

The fashion firms adopt **ecolabelling** due to

- Peer pressure from organizations such as SAC, and/or
- Environmental regulations, and/or
- The possible consumer pressure.

Ecolabelling Cost Functions

$$l_i = l_i(\sum_{k=1}^{n_R} d_{ik}), \quad i = 1, \dots, I. \tag{5}$$

- The cost associated with **ecolabelling** includes:
  - The extra labelling of the fashion product
  - The research cost associated with quantifying the emissions

Demand Prices

- E_i: the emissions generated by fashion firm i;
- E: the vector of the emissions generated by all the fashion firms.

Demand Price Functions

$$\hat{\rho}_{ik} = \hat{\rho}_{ik}(x) \equiv \rho_{ik}(d, E), \quad \forall i, \forall k. \tag{6}$$

- The functions capture the **demand-side competition** of the competitive fashion supply chain network.
- Because of **ecolabelling**, the consumers at the demand markets are now informed as to the **total emissions** generated by each of the fashion firms.

Profits

The Profit Function of Firm i

$$U_i = \sum_{k=1}^{n_R} \rho_{ik}(d, E) d_{ik} - \sum_{a \in L^i} \hat{c}_a(f, e_a(f_a)) - I_i(\sum_{k=1}^{n_R} d_{ik}). \quad (7)$$

- In this oligopoly competition problem, the strategic variables are the **product flows**.

$$X_i \equiv \{\{x_p\} | p \in P^i\} \in R_+^{n_{P^i}} \quad \text{and} \quad X \equiv \{\{X_i\} | i = 1, \ldots, I\}$$

Fashion Supply Chain Network Cournot-Nash Equilibrium

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

$$\hat{U}_i(X_i^*, \hat{X}_i^*) \geq \hat{U}_i(X_i, \hat{X}_i^*), \quad \forall X_i \in K_i, \tag{8}$$

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

An equilibrium is established if *NO* fashion firm can unilaterally improve its profit by changing its product flows, given the decisions of the other firms.

Variational Inequality Formulation

Variational Inequality (Path Flows)

Determine $x^* \in K^1$ such that:

$$\sum_{i=1}^{I} \sum_{k=1}^{n_R} \sum_{p \in P_k^i} \left[\frac{\partial \hat{C}_p(x^*)}{\partial x_p} + \frac{\partial \hat{l}_i(x^*)}{\partial x_p} - \hat{\rho}_{ik}(x^*) - \sum_{j=1}^{n_R} \frac{\partial \hat{\rho}_{ij}(x^*)}{\partial x_p} \sum_{q \in P_j^i} x_q^* \right] \times [x_p - x_p^*] \geq 0, \quad \forall x \in K^1, \tag{9}$$

where $K^1 \equiv \{x | x \in R_+^{n_P}\}$.

Variational Inequality Formulation

Variational Inequality (Link Flows)

Determine $(f^*, d^*) \in K^2$ such that:

$$\sum_{i=1}^{I} \sum_{a \in L^i} \left[\sum_{b \in L^i} \frac{\partial \hat{c}_b(f^*, e_b(f_b^*))}{\partial f_a} - \sum_{j=1}^{n_R} \frac{\partial \rho_{ij}(d^*, E)}{\partial E_i} d_{ij}^* \frac{e_a(f_a^*)}{\partial f_a} \right] \times [f_a - f_a^*]$$
$$+ \sum_{i=1}^{I} \sum_{k=1}^{n_R} \left[\frac{\partial l_i(\sum_{j=1}^{n_R} d_{ij}^*)}{\partial d_{ik}} - \rho_{ik}(d^*, E) - \sum_{j=1}^{n_R} \frac{\partial \rho_{ij}(d^*, E)}{\partial d_{ik}} d_{ij}^* \right]$$
$$\times [d_{ik} - d_{ik}^*] \geq 0, \quad \forall (f, d) \in K^2, \tag{10}$$

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

Existence

There exists at least one solution to variational inequality (9) (equivalently, to (10)), since there exists a $b > 0$, such that variational inequality

$$\langle F(X^b)^T, X - X^b \rangle \geq 0, \quad \forall X \in \mathcal{K}_b, \tag{11}$$

admits a solution in $\mathcal{K}_b$ with

$$x^b \leq b. \tag{12}$$

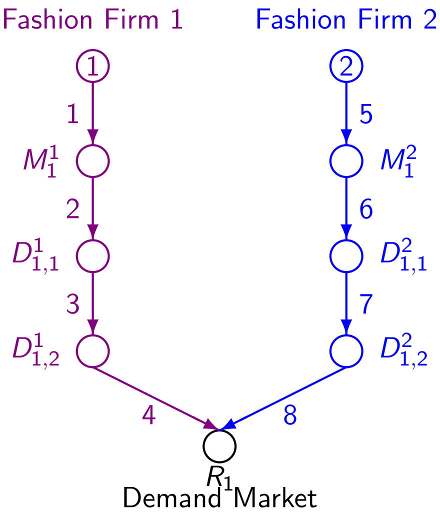
Uniqueness

With existence, variational inequality (11) and, hence, variational inequality (10) admits at least one solution. Moreover, if the function $F(X)$ of variational inequality (10) is strictly monotone on $\mathcal{K} \equiv K^2$, that is,

$$\langle (F(X^1) - F(X^2))^{\mathsf{T}}, X^1 - X^2 \rangle > 0, \quad \forall X^1, X^2 \in \mathcal{K}, \, X^1 \neq X^2, \tag{13}$$

then the solution to variational inequality (10) is unique, that is, the equilibrium link flow pattern and the equilibrium demand pattern are unique.

An Illustrative Example



- **Firm 1** is located in the U.S.:
  - Its distribution center is located in The Netherlands;
  - Air transport.
- **Firm 2** is located in Bangladesh:
  - Its distribution center is located in Germany;
  - Ship transport.
- The product is a white ladies shirt. The demand market is in Germany.

An Illustrative Example

- The emission functions reflect the total CO2 generated on links, in kilograms, associated with this product.

$$e_1(f_1) = 5f_1, \quad e_2(f_2) = 2f_2, \quad e_3(f_3) = f_3, \quad e_4(f_4) = 2.5f_4,$$

$$e_5(f_5) = 6f_5, \quad e_6(f_6) = .1f_6, \quad e_7(f_7) = 2f_7, \quad e_8(f_8) = .07f_8.$$

- The total operational cost functions are:

$$\hat{c}_1(f_1, e_1(f_1)) = 5f_1^2 + 8f_1, \quad \hat{c}_2(f_2, e_2(f_2)) = 7f_2^2 + 3f_2,$$

$$\hat{c}_3(f_3, e_3(f_3)) = 2f_3^2 + f_3, \quad \hat{c}_4(f_4, e_4(f_4)) = 2f_4^2 + 2f_4,$$

$$\hat{c}_5(f_5, e_5(f_5)) = 3f_5^2 + 4f_5, \quad \hat{c}_6(f_6, e_6(f_6)) = 3.5f_6^2 + f_6,$$

$$\hat{c}_7(f_7, e_7(f_7)) = 2f_7^2 + 5f_7, \quad \hat{c}_8(f_8, e_8(f_8)) = 1.5f_8^2 + 4f_8.$$

An Illustrative Example

- The ecolabelling cost functions are:

$$l_1(d_{11}) = .02d_{11}, \quad l_2(d_{21}) = .01d_{21}.$$

- The demand price functions for the two products at demand market R_1 are:

$$\rho_{11}(d, E) = -3d_{11} - d_{21} - .5E_1 + .2E_2 + 300,$$

$$\rho_{21}(d, E) = -4.5d_{21} - d_{11} - .5E_2 + .2E_1 + 300.$$

An Illustrative Example

	Firm 1	Firm 2
Demand	6.00	7.87
Price	255.50	239.02
Emission	62.99	64.31
Profit	872.82	1, 151.58

- Although the consumers are willing to pay more for the product from Firm 1, the profit of Firm 1 is still lower than that of Firm 2.
- Although Firm 2 emits more than Firm 1, Firm 1 is the polluter with more emissions per unit.
- Firm 2 delivers the fashion product at a lower price than Firm 1, and obtains a higher profit.

A Variant

The new demand price functions are:

$$\rho_{11}(d,E) = -3d_{11} - d_{21} + 300, \quad \rho_{21}(d,E) = -4.5d_{21} - d_{11} + 300.$$

	Firm 1	**Firm 2**
Demand	7.27	9.61
Price	268.57	249.48
Emission	76.37	78.52
Profit	1,005.00	1,339.37

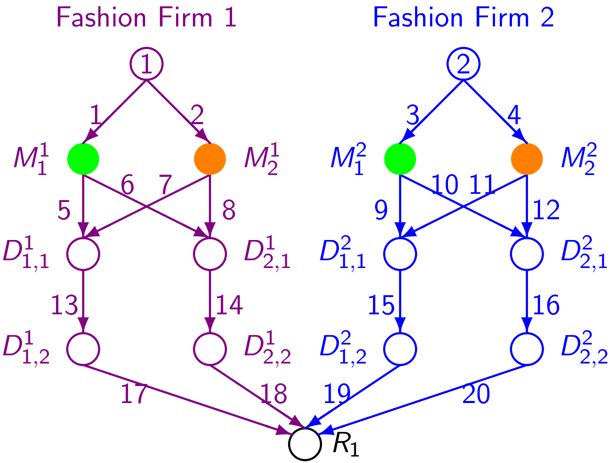
- The variant example can be interpreted, from a policy perspective as an example in which the ecolabelling cost is actually a **carbon tax**.
- The value of information provided by ecolabelling results on lower emissions.

Algorithm – Euler Method

Closed Form Expression for Product Path Flows

At iteration $\tau + 1$, for all the product path flows x_p; $p \in P_k^i$; $i = 1, \ldots, I$; $k = 1, \ldots, n_R$, compute:

$$x_p^{\tau+1} = \max\left\{0, x_p^{\tau} + a_{\tau}\left(\hat{\rho}_{ik}(x^{\tau}) + \sum_{l=1}^{n_R} \frac{\partial \hat{\rho}_{il}(x^{\tau})}{\partial x_p} \sum_{q \in P_l^i} x_q^{\tau} - \frac{\partial \hat{C}_p(x^{\tau})}{\partial x_p} - \frac{\partial \hat{I}_i(x^{\tau})}{\partial x_p}\right)\right\}. \quad (14)$$



- M_1^1 and M_1^2 are **domestic** plants in the U.S.;
- M_2^1 and M_2^2 are **off-shore** plants;
- The distribution centers and the demand market are in the U.S.
- The product is a ladies short white nightgown.

- The ecolabelling cost functions are:

$$l_1(d_{11}) = .02d_{11}, \quad l_2(d_{21}) = .02d_{21}.$$

- The demand price functions for the two products at demand market R_1 are:

$$\rho_{11}(d, E) = -3d_{11} - .5d_{21} - .5E_1 + .2E_2 + 450,$$

$$\rho_{21}(d, E) = -3d_{21} - .5d_{11} - .5E_2 + .2E_1 + 450.$$

Case Studay Example 1

Link a	$\hat{c}_a(f, e_a(f_a))$	$e_a(f_a)$	f_a^*
1	$10f_1^2 + 10f_1$	$.5f_1$	5.55
2	$f_2^2 + 7f_2$	$.8f_2$	23.44
3	$10f_3^2 + 7f_3$	f_3	4.94
4	$f_4^2 + 5f_4$	$1.2f_4$	22.68
5	$f_5^2 + 4f_5$	f_5	2.33
6	$f_6^2 + 6f_6$	f_6	3.22
7	$2f_7^2 + 30f_7$	$1.2f_7$	9.63
8	$2f_8^2 + 20f_8$	f_8	13.81
9	$f_9^2 + 3f_9$	f_9	4.94
10	$f_{10}^2 + 4f_{10}$	$2f_{10}$	0.00
11	$1.5f_{11}^2 + 30f_{11}$	$1.5f_{11}$	9.55
12	$1.5f_{12}^2 + 20f_{12}$	f_{12}	13.13
13	$f_{13}^2 + 3f_{13}$	$.1f_{13}$	11.96
14	$f_{14}^2 + 2f_{14}$	$.15f_{14}$	17.03
15	$f_{15}^2 + 1.8f_{15}$	$.3f_{15}$	14.49
16	$f_{16}^2 + 1.5f_{16}$	$.5f_{16}$	13.13
17	$2f_{17}^2 + f_{17}$	f_{17}	11.96
18	$f_{18}^2 + 4f_{18}$	$.8f_{18}$	17.03
19	$f_{19}^2 + 5f_{19}$	$1.2f_{19}$	14.49
20	$1.5f_{20}^2 + f_{20}$	$1.2f_{20}$	13.13

Case Studay Example 1

	Firm 1	Firm 2
Demand	28.99	27.62
Price	330.06	314.68
Emission	81.77	108.62
Profit	6,155.01	5,818.99

- Due to the effort of controlling its carbon emissions, Firm 1's product becomes more appealing in the demand market.
- The shipment quantity between Firm 2's domestic manufacturing plant M_1^2 and its distribution center D_2^2 is zero, mainly because this transportation activity can cause serious pollution to the environment.

Case Study: Sensitivity Analysis

Example 2

The consumers are more sensitive with respect to the generated carbon emissions:

$$\rho_{11}(d) = -3d_{11} - .5d_{21} - E_1 + .2E_2 + 450,$$
$$\rho_{21}(d) = -3d_{21} - .5d_{11} - E_2 + .2E_1 + 450.$$

Example 3

Firm 2 upgrades the manufacturing technologies at its domestic manufacturing plant M_1^2:

$$\hat{c}_3(f, e_3(f_3)) = 10f_3^2 + 10f_3, \quad e_3(f_3) = .5f_3.$$

Example 4

Firm 2 implements advanced emission-reducing manufacturing technologies at its off-shore manufacturing plant M_2^2:

$$\hat{c}_4(f, e_4(f_4)) = f_4^2 + 7f_4, \quad e_4(f_4) = .8f_4.$$

		EX 1	EX 2	EX 3	EX 4
Demands	**Firm 1**	28.99	24.20	24.17	24.13
	Firm 2	27.62	21.92	22.11	22.62
Prices	**Firm 1**	330.06	315.59	315.29	314.77
	Firm 2	314.68	299.93	301.15	302.31
Emissions	**Firm 1**	81.77	68.02	67.94	67.82
	Firm 2	108.62	85.80	84.01	81.35
Profits	**Firm 1**	6,155.01	5,121.86	5,110.89	5,091.95
	Firm 2	5,818.99	4,622.30	4,658.51	4,746.40

- A comparison of the results in Examples 1 and 2 shows that
  - The consumers' increasing environmental concerns lead to the decreases in the demands for the fashion products, as well as the prices of both products.
  - Consequently, the profits of both firms drop dramatically, while the emissions generated by both firms reduce significantly.

		EX 1	EX 2	EX 3	EX 4
Demands	Firm 1	28.99	24.20	24.17	24.13
	Firm 2	27.62	21.92	22.11	22.62
Prices	Firm 1	330.06	315.59	315.29	314.77
	Firm 2	314.68	299.93	301.15	302.31
Emissions	Firm 1	81.77	68.02	67.94	67.82
	Firm 2	108.62	85.80	84.01	81.35
Profits	Firm 1	6,155.01	5,121.86	5,110.89	5,091.95
	Firm 2	5,818.99	4,622.30	4,658.51	4,746.40

- Undoubtedly, the implementation of the advanced emission-reducing technologies could support Firm 2 to regain its competitive advantage.

- A comparison of the results in Examples 3 and 4 suggests that Firm 2 should first focus on its **off-shore manufacturing plant**, which will be more profitable.

Summary and Conclusions

- It is a rigorous, computable fashion supply chain network model that captures such notable features as
  - **Competition**,
  - **Brand differentiation**, and
  - **Ecolabelling**.
- This model allows for the investigation of the impacts of ecolabelling on firms' and consumers' behavior and responses to such a policy.
- It also enables individual firms to assess
  - Investments in emission-reducing technologies,
  - The use of alternative modes of transportation, and
  - The impacts of facility relocation.
- A special case of our model could capture **carbon taxes**.

Thank You!

For more information, see:

http://supernet.isenberg.umass.edu/