Sustainability Effort Coordination under Additive Demand

Presented by Sungyong Choi, Hanyang University

Coauthored by Brian Maeng, Pacific Lutheran University

Motivations for the models

- There is a growing consensus that carbon emission accelerates global warming.

- The reduction of carbon emission is imperative and governments are under pressure to enact legislation to curb the amount of these emissions.

- Firms are responding to the threat of such legislation or to concerns raised by their own consumers or shareholders and also undertaking initiatives to reduce their carbon footprint.

Motivations for the models (Continued)

- However, only implementing the cap-and-trade system in the level of individual firms is insufficient to reduce the carbon emission amount.

- For effective regulations, the sustainability effort (e.g. investment of cleaner technology adoption) needs to be considered in supply chains.

- Different from the previous studies, we provide a two-echelon decentralized supply chain and its centralized channel.
  - Centralized channel: maximizing the channel's total profit, both parties (manufacturer and retailer) are fully aligned by jointly determining production quantity and sustainab ility investment
  - Decentralized supply chain: Stackelberg game with leader (manufacturer; determines sustainability investment) and follower (retailer; determines; determines order quantity)

Main ideas

- Problem setting
  - Cap-and-trade systems
  - Order quantity (or production quantity) and sustainability investments are considered together
  - We extend Dong et al. (2016) by considering additive random demand

- Key contributions
  - Order quantity (or production quantity) and sustainability investments are both considered with cap-and-trade policy with additive random demand
  - The effects of some emission parameters are analyzed both in a centralized channel and decentralized supply chain.
  - Especially, the issue of SCM coordination is studied under several well-known contracts in a two-echelon supply chains.

Literature review

- Cap-and-trade policy is regarded as an effective way to mitigate climate change.
- Due to its huge impact on supply chain performance, cap-and-trade policy has been extensively discussed in the field of supply chain management .
- Hua et al. (2011) investigate how companies optimally manage inventory under carbon cap-and-trade regulation by considering the classical EOQ (Economic Order Quantity) model in a carbon emission context.
- Zhang et al. (2011) is the first paper to consider the manufacturer’s optimal production policy with a newsvendor approach (i.e. stochastic demand) un der the cap-and-trade regulation.
- Du et al. (2013) investigate a two-echelon supply chain in which the e mission-dependent manufacturer trades with emission-permit supplier under the cap-and-trade regulation.

Literature review – technology adoption

- In order to develop green SCM, various schemes have been suggested
  - Carbon emission reduction
  - Sustainability investments (e.g. making investment on cleaner technologies)
- Krass et al. (2010) consider the case where the environmental regulator as Stackelberg leader firstly decides the tax level and the firm as a follower selects emission control technology, production quantity and price.
- Drake et al. (2012) study the impact of emission tax and emissions cap-and-trade regulation on a firm's long-run technology choice and capacity decisions.

Literature review – supply chain coordination

- Supply chain coordination represents the scenario under which the decisi on making of individual supply chain players will be the same as that of a centralized channel.
- Swami and shah (2013)
  - It examines a two-echelon supply chain in which both parties can design the sustainability effort.
  - Under the deterministic demand setting, they find that a two-part tariff contract can coordinate the supply chain.
- Dong *et al.* (2016)
  - It also considers a two-echelon model with cap-and-trade.
  - The sustainability effort by the manufacturer can lead to demand expansion.
- This study
  - It extends Dong et al. (2016) by considering an additive random demand.
  - We also consider various SCM contracts and how the supply chain can be coordinated with the contracts.

Notations

- d: baseline demand of a product
- s: sustainability level determined by the manufacturer
- α: coefficient of retail price
- β: coefficient of the sustainability effect
- ξ: an error term of the baseline demand represented as a random variable with pdf f(·) and cdf F(·), defined on [A;B] with mean μ and variance σ^2
- p: unit sales price
- w: wholesale price
- c: unit production cost of a manufacturer
- v: salvage value of the product
- c_e: unit emission price of product
- c_I: sustainability investment coefficient
- a: baseline emission when sustainability level is zero
- b: carbon emission reduction coefficient
- K: total allowable carbon emission level

Model

- Demand is an additive function as described below.

$$D(p, s) = y(p, s) + \xi$$

where $y(p, s) = d - \alpha p + \beta s$, s is sustainability level and β is the parameter of the sustainability effect on increasing the demand. ξ is a random variable with pdf $f(\cdot)$ and cdf $F(\cdot)$, defined on $[A, B]$ with mean μ and variance σ^2.

Decentralized system

- Retailer problem

$$\begin{aligned}\Pi_r(p,z) &= E[p\min\{D(p,s),q\}+v\{q-D(p,s)\}^+-wq] \\ &= (p-v)E[D]-(w-v)q-(p-v)E[(D-q)^+] \\ &= (p-v)(y(p,s)+\mu)-(w-v)(y(p,s)+z)-(p-v)\int_z^B (u-z)f(u)du\end{aligned}$$

where $\{x\}^+ = max\{x,0\}$ and $z = q - y(p,s)$.

Lemma 1. *(Dada 1999) 1) If* $2r(z)^2 + r'(z) > 0$, *there exits at most two roots, and the larger of the two is the local maximizer, where* $r(z) = \frac{f(z)}{1-F(z)}$.
2) If $2r(z)^2 + r'(z) > 0$ *and* $d + \beta s - \alpha w + A > 0$, *the maximizer* z^* *is unique.*

Decentralized system (Continued)

- Manufacturer problem

$$\Pi_m = (w-c)q(p,s) - c_e\{aq(p,s) - K\} - \frac{c_I s^2}{2}$$
$$= (w-c-c_e a)q(p,s) + c_e K - \frac{c_I s^2}{2}$$

where c_e represents unit emission price.

Proposition 2. *The manufacturer's optimal sustainability level and the retailer's optimal order quantity under the decentralized system are given by*

$$s^* = \frac{(w-c-c_e a)\beta}{2c_I} \quad (4)$$
$$q^* = d + \beta s^* - \alpha p^* + z^* \quad (5)$$

Corollary 3. *Both s^* and $q^*(s^*)$ decrease in c_I and c_e.*

Centralized system

$$\Pi_c(p,s,z) = E[p\min\{D(p,s),q\} - cq + v\{q-D(p,s)\}^+ - c_e\{aq-K\} - \frac{c_I s^2}{2}] \quad (6)$$

$$= (p-v)(y(p,s)+\mu) - (c+c_e a - v)(y(p,s)+z) - (p-v)\int_z^B (u-z)f(u)du + c_e K - \frac{c_I s^2}{2}$$

$$= (p-c-c_e a)y(p,s) + (p-v)[\mu - \int_z^B (u-z)f(u)du] - (c+c_e a - v)z + c_e K - \frac{c_I s^2}{2}$$

Proposition 4. *1) If $2r(z)^2 + r'(z) > 0$, there exits at most two roots, and the larger of the two is the local maximizer, where $r(z) = \frac{f(z)}{1-F(z)}$.*
2) If $2r(z)^2 + r'(z) > 0$ and $d - \alpha(c+c_e a) + A > 0$, the maximizer z^* is unique.

Proposition 5. *The optimal price and the optimal sustainability level are given by*

$$p_c^* = \frac{d+\mu+(\alpha-\frac{\beta^2}{c_I})(c+c_e a)}{2\alpha-\frac{\beta^2}{c_I}} - \frac{\Theta(z^*)}{2\alpha-\frac{\beta^2}{c_I}} \quad (7)$$

$$s_c^* = \frac{\beta}{c_I}\frac{d+\mu-\alpha(c+c_e a)}{2\alpha-\frac{\beta^2}{c_I}} - \frac{\beta}{c_I}\frac{\Theta(z^*)}{2\alpha-\frac{\beta^2}{c_I}} \quad (8)$$

$$q_c^* = d+\beta s_c^* - \alpha p_c^* + z^* \quad (9)$$

Supply chain coordination

- Coordinated
  - Buyback contract
  - Revenue sharing contract
  - Buyback with sales rebate and penalty contract
  - Buyback with revenue sharing contract

- Not coordinated
  - Sales rebate and penalty contract
  - Revenue sharing with sales rebate and penalty contract

Contributions and future studies

- Contributions
  - Provided stylized centralized and decentralized models and various SCM coordination i ssues with cap-and-trade regulations
  - Obtained the closed-form solutions for a few models studied
  - If not, suggested the necessary conditions to satisfy in an optimal solution

- Future studies
  - Endogenous wholesale price models
  - Different risk preferences including risk aversion, loss aversion and so on