Consumer Environmental Awareness and Competition in Two-Stage Supply Chains

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Background

- A notable link has been examined between environmental and economic performance
  - E.g. positive stock market effects after announcements of environmental awards
- The higher the consumers' environmental awareness, the more the consumers are willing to pay higher prices for eco-friendly products
  - 67% of Americans agree it's important to buy products with environmental benefits and 51% say they're willing to pay more for products with environmental benefits
  - 75% of Europeans were reported as ready to buy costlier green products

Motivation

- We would to investigate the following questions:
  1. How does the consumers' environmental awareness influence the profits of the decision-makers?
  2. How does production competition intensity influence the profits of the decision-makers?
  3. How do the manufacturers decide the eco-friendly levels of their products?

Model

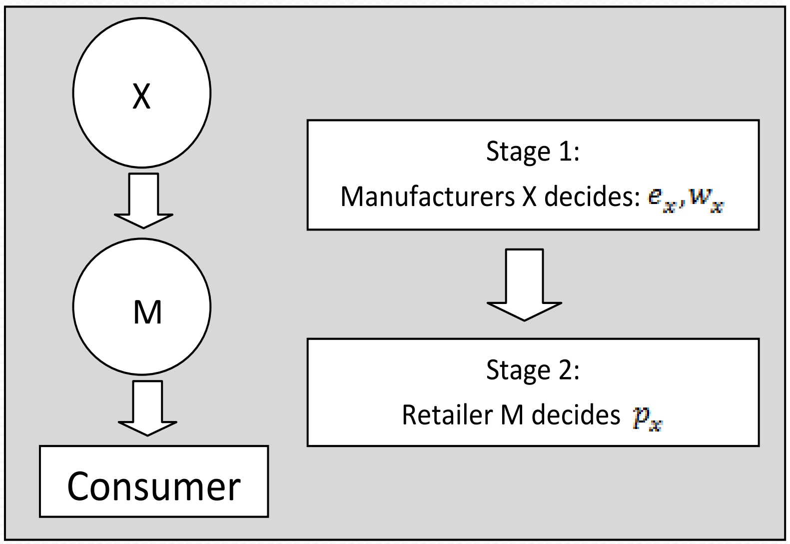
- Both the product competition between different manufacturers and the competition between retail stores;
- Two-stage Stackelberg game models to investigate the interactions between the supply chain players given three supply chain network structures.
- Three types of decision makers in the various supply chain network structures:
  - the retailer(s),
  - the manufacturer with superior eco-friendly operations,
  - the manufacturer with inferior eco-friendly operations.

Manufacturers' Production Cost Function

$$c_i + h_i e_i^2,$$

where c_i symbolizes the regular unit production cost for product i, e_i stands for the eco-friendly level of the product, and h_i represents the cost factor related to eco-friendly production and operations.

Case 1: One Manufacturer and One Retailer



Decision Variables of the Manufacturer	
e_x	Manufacturer's environmental improvement (reduction of emission per product, e.g. carbon footprint)
w_x	Manufacturer's wholesale price
Decision Variables of the Retailer	
p_x	Retail price of the product
Parameters	
c_x	Unit production cost of the Manufacturer
h_x	Manufacturer's cost parameter of environmental improvement
τ	A measure of consumers' willingness to pay higher prices for more eco-friendly products. τ is a random factor with expected value $E(\tau) = t$.

Case 1: One Manufacturer and One Retailer

- Demand Function: $d_x = a + \tau e_x - p_x.$
- Retailer's optimization problem

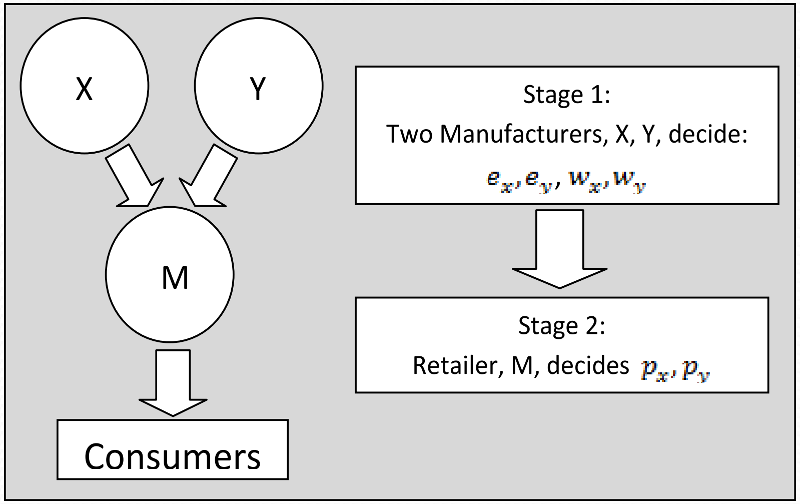
$$\text{MAX } EP_M(p_x) = E[(a + \tau e_x - p_x) \times (p_x - w_x)],$$

- Manufacturer's optimization problem

$$\text{MAX } EP_X(w_x, e_x) = E[(a + \tau e_x - p_x(w_x, e_x)) \times (w_x - c_x - h_x e_x^2)],$$

where $p_x(w_x, e_x)$ is the optimal reaction function of the Retailer given w_x and e_x.

Case 2: Two Manufacturers and One Retailer



Decision Variables of the Manufacturers	
e_x, e_y	Manufacturers' environmental improvement
w_x, w_y	Manufacturers' wholesale price
Decision Variables of the Retailer	
p_x, p_y	Retail price for products x and y
Parameters	
c_x, c_y	Unit production cost of the manufacturers
h_x, h_y	Manufacturers' cost parameter of environmental improvement
τ	A measure of consumers' willingness to pay higher prices for more eco-friendly products. τ is a random factor with expected value $E(\tau) = t$.
k	A measure of the intensity of the product competition

Case 2: Two Manufacturers and One Retailer

- Demand function:

$$d_x = a + \tau\big(e_x - k(e_y - e_x)\big) - p_x + k(p_y - p_x),$$
$$d_y = a + \tau\big(e_y - k(e_x - e_y)\big) - p_y + k(p_x - p_y),$$

- Retailer's optimization function:

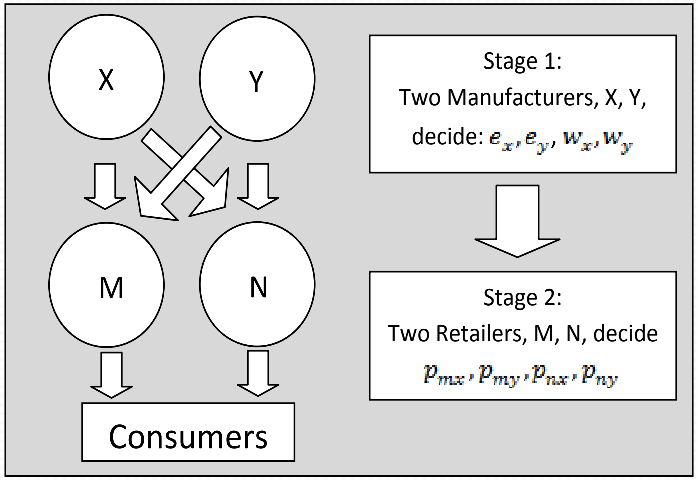
$$\text{MAX } EP_M(p_x, p_y) = E\Big[[a + \tau\Big(e_x - k(e_y - e_x)\Big) - p_x + k(p_y - p_x)] \times (p_x - w_x) + [a + \tau\Big(e_y - k(e_x - e_y)\Big) - p_y + k(p_x - p_y)] \times (p_y - w_y)\Big],$$

- Manufacturers' optimization functions:

$$\text{MAX } EP_M(w_x, e_x) = E\big[[a + \tau\big(e_x - k(e_y - e_x)\big) - p_x\big(w_x, e_x, w_y, e_y\big) + k(p_y\big(w_x, e_x, w_y, e_y\big) - p_x(w_x, e_x, w_y, e_y))] \times (w_x - c_x - h_x e_x^2)\big]$$

where $p_x(w_x, e_x, w_y, e_y)$ and $p_x(w_x, e_x, w_y, e_y)$ are the optimal reaction functions of the Retailer given $w_x, e_x, w_y,$ and e_y. The optimization problem of Manufacturer Y can be defined in a symmetric fashion.

Case 3: Two Manufacturers and Two Retailers



Decision Variables of the Manufacturers	
e_x, e_y	Manufacturers' environmental improvement
w_x, w_y	Manufacturers' wholesale prices
Decision Variables of the Retailers	
p_{mx}, p_{my} p_{nx}, p_{ny}	Retailers M and N's Retail prices for products x and y
Parameters	
c_x, c_y	Unit production cost of the manufacturers
h_x, h_y	Manufacturers' cost parameter of environmental improvement
τ	A measure of consumers' willingness to pay higher prices for more eco-friendly products. τ is a random factor with expected value $E(\tau) = t$.
k	A measure of the intensity of the product competition
r	A measure of the intensity of the retail competition

Case 3: Two Manufacturers and Two Retailers

- Demand function

$$d_{mx} = a + \tau\big(e_x - k(e_y - e_x)\big) - p_{mx} + k(p_{my} - p_{mx}) + r(p_{nx} - p_{mx}),$$

$$d_{my} = a + \tau\left(e_y - k(e_x - e_y)\right) - p_{my} + k(p_{mx} - p_{my}) + r(p_{ny} - p_{my}),$$

- Retailer M's optimization function:

$$\text{MAX } EP_M(p_{mx}, p_{my}) = E\Big[\big[a + \tau\left(e_x - k(e_y - e_x)\right) - p_{mx} + k(p_{my} - p_{mx}) + r(p_{nx} - p_{mx})\big] \times (p_{mx} - w_x) + \big[a + \tau\left(e_y - k(e_x - e_y)\right) - p_{my} + k(p_{mx} - p_{my}) + r(p_{ny} - p_{my})\big] \times (p_{my} - w_y)\Big].$$

Case 3: Two Manufacturers and Two Retailers

- Manufacturer X's optimization function

$$\text{MAX}\, EP_X(w_x, e_x) = E[(d_{mx} + d_{nx}) \times (w_x - c_x - h_x e_x^2)],$$

which is equivalent to

$$\begin{aligned}
&\text{MAX}\, EP_X(w_x, e_x) \\
&\qquad = E\Big[[a + \tau\big(e_x - k(e_y - e_x)\big) - p_{mx}(w_x, e_x, w_y, e_y) \\
&\qquad + (p_{my}(w_x, e_x, w_y, e_y) - p_{mx}(w_x, e_x, w_y, e_y) \\
&\qquad + r(p_{nx}(w_x, e_x, w_y, e_y) - p_{mx}(w_x, e_x, w_y, e_y))) + (a \\
&\qquad + \tau\big(e_x - k(e_y - e_x)\big) - p_{mx}(w_x, e_x, w_y, e_y) \\
&\qquad + (p_{my}(w_x, e_x, w_y, e_y) - p_{mx}(w_x, e_x, w_y, e_y)) \\
&\qquad + r(p_{nx}(w_x, e_x, w_y, e_y) - p_{mx}(w_x, e_x, w_y, e_y)))] \times (w_x - c_x - h_x e_x^2)\Big]
\end{aligned}$$

Equilibrium Results (Case 1)

Theorem 1: There exists a unique solution to the model in Case 1.

The optimal decision for the Manufacturer is:

$$e_x^* = \frac{t}{2h_x},$$

$$w_x^* = \frac{4 + \frac{3t^2}{h_x} + 4a}{8}.$$

The optimal decision for the Retailer is:

$$p_x^* = \frac{4c + \frac{7t^2}{h_x} + 12a}{16}.$$

Equilibrium Results (Case 1)

Proposition 1: When the consumer environmental awareness, t, increases, both the retailer's and the manufacturer's profits will increase.

Proposition 2: When the cost factor of eco-friendly production, h_x, decreases, the product's eco-friendly level will increase, and the cost related to eco-friendly production will also increase.

Equilibrium Results (Case 2)

Theorem 2: There exists a unique solution to the model in Case 2.

The optimal solution for Manufacturer X is:

$$e_x^* = \frac{t}{2h_x},$$

$$w_x^* = \frac{(8 + 20k + 12k^2)c + \left((6 + 12k + 4k^2)\frac{1}{h_x} - (k^2 + k)\frac{1}{h_y}\right)t^2 + (12k + 8)a}{4(4 + 8k + 3k^2)}.$$

The optimal solution for Manufacturer Y is:

$$e_y^* = \frac{t}{2h_y},$$

$$w_y^* = \frac{(8 + 20k + 12k^2)c + \left((6 + 12k + 4k^2)\frac{1}{h_y} - (k^2 + k)\frac{1}{h_x}\right)t^2 + (12k + 8)a}{4(4 + 8k + 3k^2)}$$

Equilibrium Results (Case 2)

The optimal solution for the Retailer is:

$$p_x^* = \frac{(8+20k+12k^2)c + \left((14+28k+10k^2)\frac{1}{h_x} - (k^2+k)\frac{1}{h_y}\right)t^2 + (24+44k+12k^2)a}{8(4+8k+3k^2)},$$

$$p_y^* = \frac{(8+20k+12k^2)c + \left((14+28k+10k^2)\frac{1}{h_y} - (k^2+k)\frac{1}{h_x}\right)t^2 + (24+44k+12k^2)a}{8(4+8k+3k^2)}.$$

Equilibrium Results (Case 2)

Proposition 3: When the consumer environmental awareness, t, increases, the profits of both the retailer and the manufacturer with superior eco-friendly operations (Manufacturer Y) will increase; the profit of the manufacturer with inferior eco-friendly operations (Manufacturer X) will increase, if the ratio of the two manufacturers' eco-friendly production cost factors, $z=\frac{h_y}{h_x}$, is greater than z^*, and will decrease if z is less than z^*, where $z^*=\frac{k(1+k)}{k^2+4k+2}$.

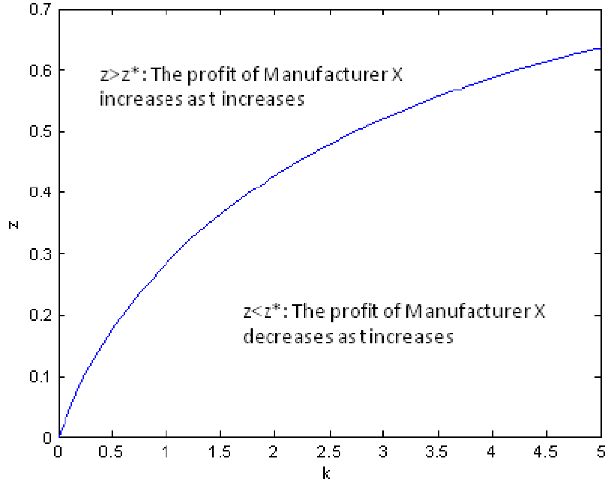


Figure 4: The z^* Curve for Case 2

Equilibrium Results (Case 2)

Proposition 4: When the intensity of product competition, k, increases, the Retailer's profit will increase while the profit of the manufacturer with inferior eco-friendly operations (Manufacturer X) will decrease; the profit of the manufacturer with superior eco-friendly operations (Manufacturer Y) will increase, if the ratio of the two manufacturers' eco-friendly production cost factors, z, is less than z', and will decrease if z is greater than z', where

$$z' = \frac{t^2(12k^3+8+26k^2+3k^4+24k)}{16h_x(a-c)k+48h_x k^2(a-c)+36h_x k^3(a-c)+8t^2+21t^2k^3+28t^2k+38t^2k^2+3t^2k^4}$$

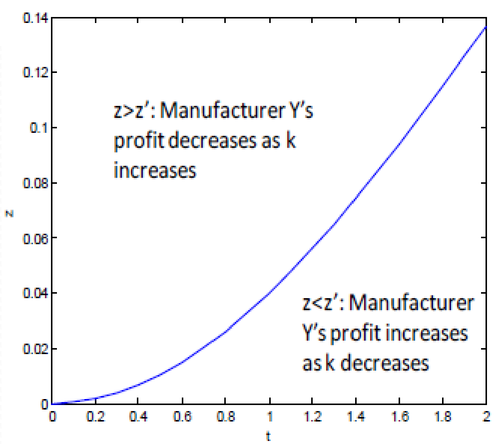


Figure 7: The z' Curve for Case 2

Equilibrium Results (Case 2)

Proposition 5: The manufacturer with superior eco-friendly operations (Manufacturer Y) produces more eco-friendly products, and incurs higher costs related to improvement of the environmental aspect of the product.

Equilibrium Results (Case 3)

Theorem 3: There exists a unique solution to the model in Case 3.

Proposition 6: When consumer environmental awareness, t, increases, the profits of both the Retailer and the manufacturer with superior eco-friendly operations (Manufacturer Y) will increase; the profit of the manufacturer with inferior eco-friendly operations (Manufacturer X) will increase if the ratio of the two manufacturers' eco-friendly production cost factors, z, is greater than z^*, and will decrease if z is less than z^* where

$$z^* = \frac{k(4k^3r^2+16k^3r+16k^3+4k^2r^3+24k^2r^2+48k^2r+32k^2+kr^4+10kr^3+30kr^2+40kr+20k+r^4+5r^3+10r^2+10r+4}{k(104r^2+120r+48+36r^3+4r^4)+k^2(100+200r+28r^3+128r^2+r^4)+k^3(80+4r^3+4r^2+120r+4r^2)+k^4(16+16r)+12r^3+2r^4+24r+8+r^2}.$$

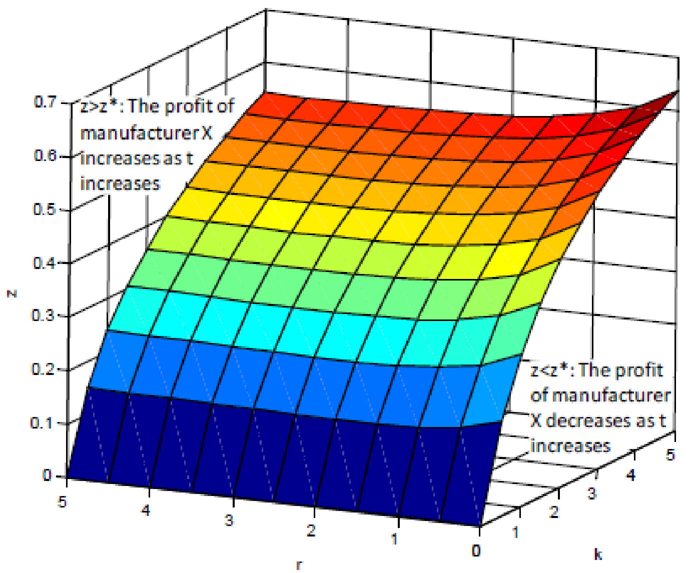


Figure 5: The z^* Surface for Case 3

Proposition 7: When the intensity of production competition, k, increases, the retailer's profit will increase while the profit of the manufacturer with inferior eco-friendly operations (Manufacturer X) will decrease; the profit of the manufacturer with superior eco-friendly operations (Manufacturer Y) will increase if the ratio of the two manufacturers' eco-friendly production cost factors, z, is less than z', and will decrease if z is greater than z', where the form of z' is provided in Appendix B.

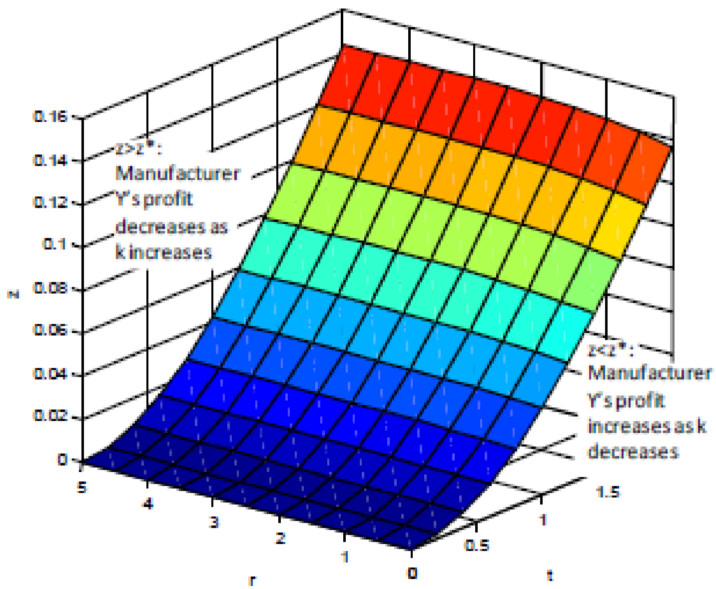


Figure 8: The Surface of z' in Case 3

Numerical Example 1

- In Example 1, we show how the prices of the two products differentiate as the gap between the cost factors becomes larger. In particular, we use the model in Case 3, and specify the parameters as follows: a = 10, c = 3, h_x= 2, t = 2, r = 2, and k = 2. Since h_y=z*h_x, we vary the value of h_y by changing z from 1 to 0.1.

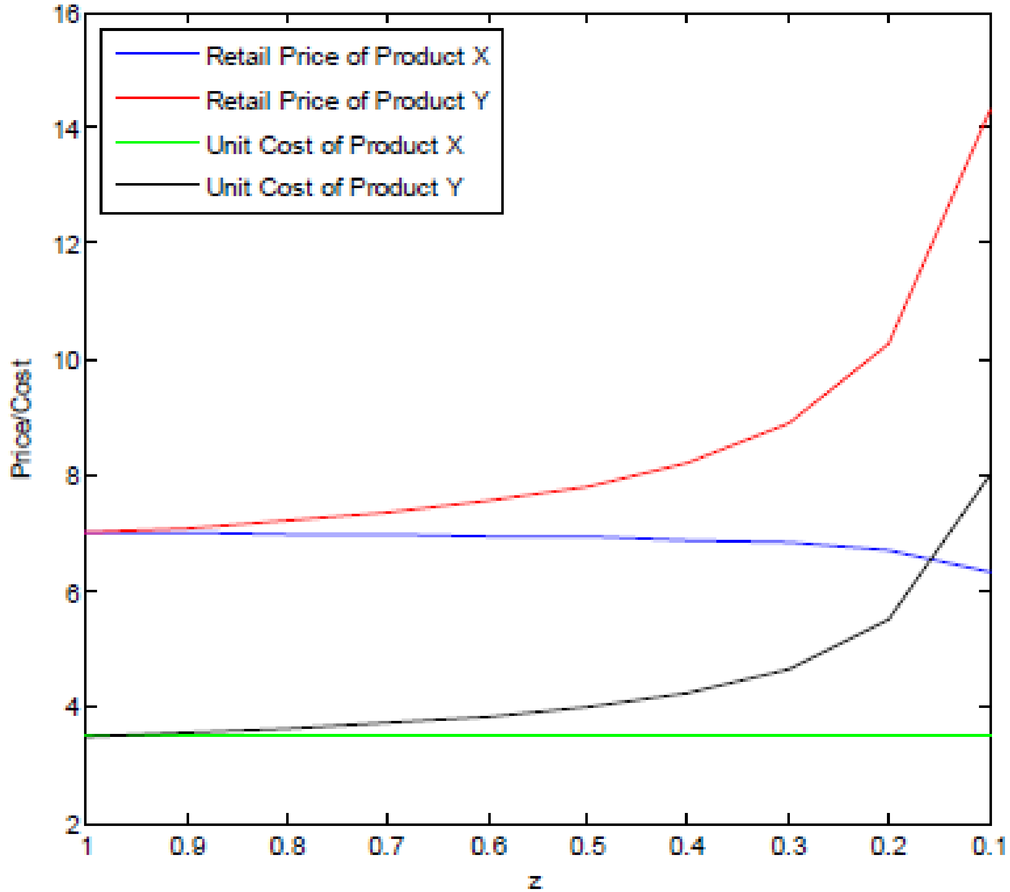
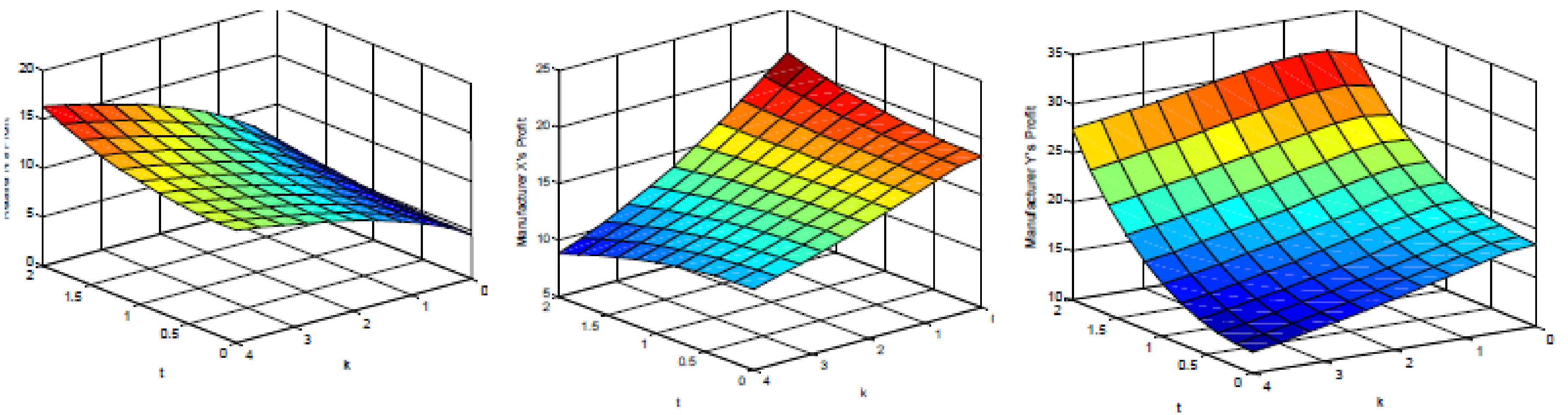


Figure 6: Retail Prices and Costs of the Two Products as z Decreases

Numerical Example 2

- We now provide a numerical example that shows the profits of various decision-makers under different levels of product competition, *k*, and consumers' environmental awareness, *t*. We utilize the model in Case 3 and specify the parameters as follows: $a = 10$, $c = 3$, $h_x = 2$, $h_y = 0.5$, and $r = 2$.



a) The Profit of Retailer N under Different Levels of t and k

b) The Profit of Manufacturer X under Different Levels of t and k

c) The Profit of Manufacturer Y under Different Levels of t and k

Figure 9: The Profit of Retailer N, Manufacturer X, and Manufacturer Y under Different Levels of *t* and *k*

Managerial Insights and Conclusion

- **Q1: How does the consumers' environmental awareness influence the profits of the decision-makers in the three supply chain network structures?**

- When consumers' environmental awareness increases, the profits of superior eco-friendly manufacturers and retailers will rise
- When consumers' environmental awareness increases, the profit of inferior eco-friendly companies may increase if they can reduce the gap of cost factors for eco-friendly production, or, if they are able to increasingly differentiate their products to reduce the intensity of the product competition. Moreover, the manufacturers with inferior eco-friendly operations can possibly benefit from a more competitive retail environment, which may make their profits increase as consumers' environmental awareness rises.

Managerial Insights and Conclusion

- **Q2: How does production competition intensity influence the profits of the decision-makers in the three supply chain network structures?**

- Our results also show that, under higher product and price competition, retailers are better off if they sell products from eco-friendly manufacturers and non eco-friendly manufacturers. On the other hand, manufacturers with higher cost factors for eco-friendly production are less profitable under this scenario. As for the manufacturers with superior eco-friendly operations, their profitability also tends to decrease unless they have significant cost advantages in terms of eco-friendly production and consumers are willing to pay a higher premium for their products.

Managerial Insights and Conclusion

- **Q3: How do the manufacturers decide the eco-friendly levels of their products?**

- The manufacturer with superior eco-friendly operations produces more eco-friendly products and incurs higher costs related to the improvement of the environmental aspect of the product.