Closed-Loop Supply Chain Models with Product Remanufacturing

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Closed Loop Supply Chains

- Collection of used products for remanufacturing

  Why?
- Reduction in manufacturing costs through reuse of parts and materials.
- Legislation (Europe, N. America, Japan)

Modes of collection

- Manufacturers collect the used products directly from the customers.
- Xerox collects used cartridges, saving 40%-65% in manufacturing costs.
- Hewlett-Packard – Computers and Peripherals
- Canon- Print and copy cartridges.

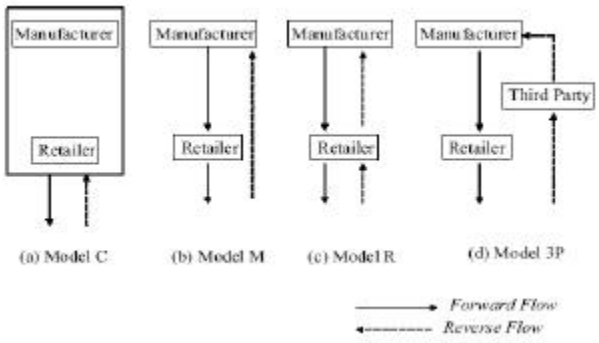
Modes of Collection (Contd.)

- Manufacturers utilize retailers to collect used products.
- Kodak receives single-use cameras from large retailers. 76% by weight of a used camera is reused in producing a new one.
- Several mobile phone manufacturing companies.

Modes of Collection (Contd.)

- Independent third parties handle used-product collection for OEMs.
- Auto Industry – Big three
- Third parties like GENCO are used by some consumer goods manufacturers.

Modes of collection



- C: Centralized system
- M: Collection by Manufacturer
- R: Collection by Retailer
- 3P: Collection by 3rd Party

Assumptions

- Cost of remanufacturing is less than cost of producing a new product.
- Manufacturer has sufficient channel power to act as a Stackelberg leader.
- All players have access to the same information.
- The closed loop supply chain decisions are considered in a single period setting.
- The remanufactured products are as good as the new ones.

Notations used in the model

- C_m : Unit cost of manufacturing a new product
- C_r: Unit cost of remanufacturing a returned product
- p: Retail price of the product
- w: Wholesale price
- b: Unit transfer price of a returned product from retailer/3P to manufacturer
- D(p): Demand of the product as a function of price
  D(p) = F – ? p (downward sloping linear demand function)
- Π_j: Profit function for channel member j in model i.
  j: M,R,3P
  i: C,M,R,3P

Notations (Contd.)

- τ : Return rate of used products from customers. $0 = \tau = 1$

  $\tau = v(I/C_L)$ where C_L is a scaling parameter.
- I: Investment in collection activities.
- C: Average unit cost of manufacturing:

  $C = Cm(1-\tau) + Cr\,\tau$
- ?: Unit cost savings from reuse:

  $? = Cm - Cr$? $C = (Cm - \tau\,?)$
- A: Variable unit cost of collecting and handling a returned product. (A< ?)
- $C(\tau)$: Total cost of collection

  $C(\tau) = I + A\,\tau\ D(p) = C_L\,\tau^2 + A\,\tau\ D(p)$

Model C: Centrally Coordinated System

$$\underset{p,\tau}{\text{Max}}\,\Pi^C = (\phi - \beta p)[p - c_m + \tau\Delta] - C_L\tau^2 - A\tau(\phi - \beta p).$$

Demand

(Unit Price) – (Unit manufacturing cost)

Total Cost of collection

Simultaneous solution of FOC gives:

$$p^{*C} = \frac{\phi + \beta c_m}{2\beta} - \frac{1}{2}(\Delta - A)^2 \frac{\phi - \beta c_m}{4C_L - \beta(\Delta - A)^2}$$

$$\tau^{*C} = \frac{(\phi - \beta c_m)(\Delta - A)}{4C_L - \beta(\Delta - A)^2}.$$

Model M: Manufacturer Collecting

$$\text{Max}_p \Pi_R^M = (p - w)(\phi - \beta p)$$

Retailer's FOC characterizes the unique best response: $p^{*M} = (\phi + \beta w)/(2\beta)$

Retailer's demand function: $D(w) = (\phi - \beta w)/2$

$$\underset{w,\tau}{\text{Max}}\, \Pi_M^M = \frac{\phi - \beta w}{2}[w - c_m + \tau\Delta] - C_L\tau^2 - A\tau\frac{\phi - \beta w}{2}$$

Manufacturer's FOC characterizes the unique best response:

$$w^{*M} = \frac{\phi + \beta c_m}{2\beta} - \frac{(\Delta - A)^2(\phi - \beta c_m)}{2[8C_L - \beta(\Delta - A)^2]}$$

$$\tau^{*M} = \frac{(\phi - \beta c_m)(\Delta - A)}{8C_L - \beta(\Delta - A)^2}.$$

Model R: Retailer Collecting

$$\text{Max}_{p,\tau} \Pi_R^R = (\phi - \beta p)[p - w] + b\tau(\phi - \beta p) - C_L\tau^2 - A\tau(\phi - \beta p)$$

Best response from FOC:

$$p^{*R} = (\phi + \beta[w - (b - A)\tau^*])/(2\beta)$$

$$\tau^{*R} = ((b - A)/(2C_L))(\phi - \beta p^{*R})$$

$$\underset{w}{\text{Max}}\, \Pi_M^R = (\phi - \beta p^{*R})[w - c_m + \Delta\tau^{*R}] - b\tau^{*R}(\phi - \beta p^{*R})$$

From FOC, for a given b:

$$w^{*R} = \frac{\phi + \beta c_w}{2\beta} - \frac{(\Delta - b)(b - A)(\phi - \beta c_w)}{2[4C_L - \beta(\Delta - A)(b - A)]}$$

Model 3P: Third party Collecting

$$\text{Max}_{\tau}\ \Pi_{3P}^{3P} = b\tau(\phi - \beta p^{*3P}) - C_L\tau^2 - A\tau(\phi - \beta p^{*3P})$$

FOC gives:

$$\tau^{*3P} = ((b - A)/(2C_L))(\phi - \beta p^{*3P})$$

$$\underset{w}{\text{Max}}\ \Pi_M^{3P} = (\phi - \beta p^{*3P})[w - c_m + (\Delta - b)\tau^{*3P}]$$

From FOC, Manufacturer sets wholesale price as:

$$w^{*3P} = \frac{\phi + \beta c_m}{2\beta} - \frac{\phi - \beta c_m}{2\beta}\left[\frac{\beta(b-A)(\Delta - b)/(4C_L)}{1 - \beta(b-A)(\Delta - b)/(4C_L)}\right]$$

Comparison- Product Return Rates

- $t^{*C} > t^{*R} > t^{*M} > t^{*3P}$
- The centrally coordinated system leads to highest investment level in collection, because decisions are fully coordinated in the system.
- Model M has lower product return rate than Model R because the retailer has a direct effect on demand because of his pricing strategy, while the manufacturer only has an indirect effect. Both have same marginal gains from investing in increasing t.
- The closer the agent is to the market, the more efficient is the used product collection for all parties involved.

Comparison – Retail Prices

- $p^{*C} < p^{*R} < p^{*M} < p^{*3P}$
- 3P: Investment benefits only 3rd party directly. Only 2nd order effect in retail price in the form of lower wholesale price.
- M: Lower w? Increased demand ? Increased savings through remanufacturing.
- R: Retailer can directly reflect the unit cost savings in the final demand through pricing decision.
- C: Lowest as gains in efficiency from coordinating can be shared with markets to increase demand and profits.

Comparison - Profits

- Manufacturer's Profits:
  $(?_M)^{*R} > (?_M)^{*M} > (?_M)^{*3P}$
- Retailer's Profits:
  $(?_R)^{*R} > (?_R)^{*M} > (?_R)^{*3P}$
- Total system profits:
  $?^{*C} > ?^{*R} > ?^{*M} > ?^{*3P}$
- Benefits to society, in terms of increased return rate and increased ability to buy the products complement the increased profits in the C and R models.

Comparison:

Channel decision and profits	R Model	M Model	SP Model
Π_T^*	$\frac{(3/4)(\phi-\beta c_m)^2/(4\beta)}{[1-\beta(\Delta-A)^2/(4C_L)]}$	$\frac{[(\phi-\beta c_m)^2/(4\beta)][3/4-\beta(\Delta-A)^2/(16C_L)]}{[1-\beta(\Delta-A)^2/(8C_L)]^2}$	$\frac{[(\phi-\beta c_m)^2/(4\beta)][3/4-\beta(\Delta-A)^2/(64C_L)]}{[1-\beta(\Delta-A)^2/(16C_L)]^2}$
p^*	$\frac{[3C_L-\beta(\Delta-A)^2][\phi+\beta C_L c_m}{\beta[4C_L-\beta(\Delta-A)^2]}$	$\frac{3\phi+\beta c_m}{4\beta}-\frac{(\phi-\beta c_m)(\Delta-A)^2}{4[8C_L-\beta(\Delta-A)^2]}$	$\frac{3\phi+\beta c_m}{4\beta}-\frac{(\phi-\beta c_m)(\Delta-A)^2}{4[16C_L-\beta(\Delta-A)^2]}$
τ^*	$\frac{(\phi-\beta c_m)(\Delta-A)}{8C_L-2\beta(\Delta-A)^2}$	$\frac{(\phi-\beta c_m)(\Delta-A)}{8C_L-\beta(\Delta-A)^2}$	$\frac{(\phi-\beta c_m)(\Delta-A)}{[16C_L-\beta(\Delta-A)^2]}$
w^*	$\frac{\phi+\beta C_L}{2\beta}$	$\frac{\phi+\beta c_m}{2\beta}-\frac{(\Delta-A)^2[\phi-\beta c_m]}{2[8C_L-\beta(\Delta-A)^2]}$	$\frac{\phi+\beta c_m}{2\beta}-\frac{(\phi-\beta c_m)(\Delta-A)^2}{2[16C_L-\beta(\Delta-A)^2]}$
Π_M^*	$\frac{(\phi-\beta c_m)^2/(8\beta)}{[1-\beta(\Delta-A)^2/(4C_L)]}$	$\frac{(\phi-\beta c_m)^2/(8\beta)}{[1-\beta(\Delta-A)^2/(8C_L)]}$	$\frac{(\phi-\beta c_m)^2/(8\beta)}{[1-\beta(\Delta-A)^2/(16C_L)]}$
Π_R^*	$\frac{(\phi-\beta c_m)^2}{16\beta[1-\beta(\Delta-A)^2/(4C_L)]}$	$\frac{(\phi-\beta c_m)^2}{16\beta[1-\beta(\Delta-A)^2/(8C_L)]^2}$	$\frac{(\phi-\beta c_m)^2/(16\beta)}{[1-\beta(\Delta-A)^2/(16C_L)]^2}$
Π_{SP}^*	N/A	N/A	$\frac{[(\phi-\beta c_m)^2/(16\beta)]\beta(\Delta-A)^2/(16C_L)}{[1-\beta(\Delta-A)^2/(16C_L)]^2}$

Future Research

Relax assumptions like:

- Presence of infrastructure for logistics of product collection.
- Single agent performing the collection.
- Proximity of agent to consumers.
- Equal investment for all agents.
- Usability of all returned products.
- Remanufacturing by someone other than the original manufacturer.