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

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Centralized system</td>
</tr>
<tr>
<td>M</td>
<td>Collection by Manufacturer</td>
</tr>
<tr>
<td>R</td>
<td>Collection by Retailer</td>
</tr>
<tr>
<td>3P</td>
<td>Collection by 3rd Party</td>
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</table>

(a) Model C  (b) Model M  (c) Model R  (d) Model 3P

Forward Flow  Reverse Flow

- 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
  \[ D(p) = F - \beta p \] (downward sloping linear demand function)
- $\pi_{ij}$: Profit function for channel member $j$ in model $i$.
  - $j$: M,R,3P
  - $i$: C,M,R,3P
Notations (Contd.)

- $t$: Return rate of used products from customers. $0 = t = 1$
  \[ t = \frac{v}{I/C_L} \] where $C_L$ is a scaling parameter.
- $I$: Investment in collection activities.
- $C$: Average unit cost of manufacturing:
  \[ C = C_m(1 - t) + Cr \]
- $?$: Unit cost savings from reuse:
  \[ ? = C_m - Cr \] \[ C = (C_m - \phi) \]
- $A$: Variable unit cost of collecting and handling a returned product. \[ A < \phi \]
- $C(t)$: Total cost of collection
  \[ C(t) = I + At + D(p) = C_L t^2 + At + D(p) \]

Model C: Centrally Coordinated System

Max $\Pi^C = (\phi - \beta p)(b - c_m + \tau \Delta) - C_L \tau^2 - A \tau(\phi - \beta p)$.

Simultaneous solution of FOC gives:

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

$\tau^C = \frac{(\phi - \beta c_m)(\Delta - A)}{4C_L - \beta(\Delta - A)^2}$
Model M: Manufacturer Collecting

\[ \max_p \Pi^M_R = (p - w)(\phi - \beta p) \]
Retailer’s FOC characterizes the unique best response: \( p^{*M} = (\phi + \beta w)/(2\beta) \)
Retailer’s demand function: \( D(w) = (\phi - \beta w)/2 \)

\[ \max_{\omega, \tau} \Pi^M_M = \frac{\phi - \beta w}{2} \left[ w - c_m + \tau \Delta \right] - \tau \frac{\phi - \beta w}{2} \\
\]
Manufacturer’s FOC characterizes the unique best response:

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

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

Model R: Retailer Collecting

\[ \max_p, \Pi^R_R = (\phi - \beta p)(p - w) + b\tau(\phi - \beta p) - C_L \tau^2 - A\tau(\phi - \beta p) \]
Best response from FOC:

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

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

\[ \max_{\omega} \Pi^R_M = (\phi - \beta p^{*R})(w - c_m + \Delta \tau^{*R}) - b\tau^{*R}(\phi - \beta p^{*R}) \]
From FOC, for a given \( b \):

\[ \omega^{*R} = \frac{\phi + \beta c_m}{2\beta} \frac{(\Delta - b)(b - A)\phi - \beta c_m)}{2[4C_L - \beta(\Delta - A)(b - A)]} \]
Model 3P: Third party Collecting

\[ \hat{\text{Max}}, \Pi_{3P} = h \tau (\phi - \beta p^{3P}) - C_L \tau^2 - A \gamma (\phi - \beta p^{3P}) \]

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

\[ \text{Max} \Pi_{3P} = (\phi - \beta p^{3P})[\hat{\omega} - c_m + (\Delta - b) \tau^{3P}] \]

From FOC, Manufacturer sets wholesale price as:

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

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.
- 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:
- 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:

<table>
<thead>
<tr>
<th>Channel/Optimal and profits</th>
<th>F Model</th>
<th>M Model</th>
<th>SF Model</th>
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<tr>
<td>$F$</td>
<td>$\frac{(\lambda / \mu) \cdot (x - \lambda / \mu)^2 \cdot (x)}{[1 - \lambda / \mu + \lambda / \mu] \cdot (x)}$</td>
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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.