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Reverse Channel Design: Profitability vs. Environmental Benefits

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Environmental issues are a growing priority in supply chain management, which has heightened the interest in remanufacturing. A key attribute of a remanufacturing strategy is the division of labor in the reverse channel, especially whether the remanufacturing should be performed in-house or outsourced to a third party. We investigate this decision for a retailer who accepts returns of a remanufacturable product. Our formulation considers the relative cost-effectiveness of the two approaches, uncertainty in the input quality of the collected/returned used products, consumer willingness-to-pay for remanufactured product, and the extent to which the remanufactured product cannibalizes demand for new product. Our analysis predicts the retailer's propensity to remanufacture, which provides a metric of the environmental impact of each strategy.

Keywords: Reverse Channel Design, Remanufacturing, Outsourcing,
Environmental Impact

1 Introduction

Sustainability initiatives are at the forefront of many firms' agendas today. Consumers and government mandates are both calling for environment-friendly business practices. Remanufacturing is one approach to sustainability, with benefits that include the diversion of discarded products from landfills, reduced virgin raw material usage, and energy consumption lower than in original manufacturing (U.S. EPA 1997). It is perceived as an environment-friendly end-of-use management option for many product categories (Örşdemir, et al 2014). For example, remanufacturing in the auto industry saves over 80% of the energy and raw material required to manufacture a new part, and keeps used parts ("cores") out of landfills. Gutowski, et al (2011) find that remanufacturing consumes less energy than does manufacturing of new products, and evidence suggests that remanufacturing can be superior to recycling in material consumption and overall environmental impact (Fullerton and Wu, 1989). Remanufactured products can be made to perform as well as new products.

GameStop, the consumer electronics retailer that specializes in video-game consoles, motivates our study. The company's retail stores serve as collection centers for used game consoles. Collected consoles are sent to a facility dedicated to testing and refurbishing. Those consoles that undergo refurbishing are sent back to the retail stores to be sold for less than the retail price of new consoles. These less expensive consoles help the company reach consumers who could not or would not buy the product new, and also stimulate the sales of a complementary product carried by GameStop, i.e., game software. Success in this part of the business model

has motivated the company to increase collections (by offering store credits or cash for used consoles), and build its own remanufacturing facility in Grapevine, Texas.

Superiority of an in-house approach to remanufacturing in-house is not a foregone conclusion. A significant number of third-party firms offer remanufacturing/refurbishing expertise, making viable the outsourcing of these activities. As a general business practice, outsourcing is attractive due to its avoidance of direct ownership of workforce, assets, and infrastructure, which increases financial and operational flexibility. Outsourcing may also provide access to specialized and focused expertise. Disadvantages include a possible reduction in product quality, communication and coordination difficulties, and the possibility of the third-party emerging as a competitor by leveraging its inside access to proprietary product and process knowledge (Tsay 2014).

This paper evaluates whether a retailer such as GameStop should remanufacture in-house or outsource this reverse channel activity, an important question which has received little attention in the literature. As we are interested in more than the retailer profitability that results from each alternative, we also consider the environmental consequences.

Our analysis has several noteworthy features. First, the problem we address is grounded in reality. Choosing to remanufacture in-house or outsource the process is not only relevant for GameStop (as can be seen in our motivating example) but it is becoming increasingly relevant for other firms who currently perform these activities in-house (see, for example, Martin, et al, 2010). Second, the choice of reverse channel explicitly incorporates the volume of collected products available for remanufacturing. Third, we

consider uncertainty in the quality of collected products, which makes the cost of each strategy a function of this quality level. Fourth, we endogenize the specification of a base-line quality level for qualifying for remanufacture. This allows prediction of the percentage of collected products that will be remanufactured, providing a measure of environmental impact. Finally, our model of consumer behavior incorporates the possibility that remanufactured product may cannibalize the sales of the new product.

The remainder of this paper is organized as follows. The next section reviews the relevant literature. Section 3 formulates a model of each approach to remanufacturing. Section 4 presents our structural analysis and managerial insights. Section 5 analyzes the impact of the remanufacturing strategies on the environment and proposes an approach that can align profit and environmental objectives. Finally, Section 6 discusses implications of this research and concludes the paper.

2 Relevant Literature

Guide and Van Wassenhove (2009), Tang and Zhou (2012), and Souza (2013) provide broad reviews of extant literature on reverse supply chains. This section comments specifically on the four distinguishing features that position our research in this literature: (1) consumer choice, (2) uncertainty in product returns, (3) in-house versus outsourced remanufacturing, and (4) the environmental impact of remanufacturing.

In the area of consumer choice, the vertical differentiation framework has been used to examine whether an OEM should offer remanufactured ver-

sions of its products. Our paper also uses a vertical differentiation framework to depict cannibalization. Consumers in our model value the remanufactured product less than they do the new product, but the valuation is based on perception rather than any real difference in quality.

Uncertainty in the quality and quantity of returns is a major concern in product recovery. Guide and Van Wassenhove (2009) observe that the decision to introduce a remanufactured product depends more on market (demand) or supply (quantity and quality) constraints than on technical operating constraints. We align with this research by treating the quantity of product returns as exogenous (in a deterministic way). Following these observations we allow incoming product return quality to be stochastic and consider remanufacturing costs to be a function of the quality level of the used products. In addition, we endogenize the retailer determination of the base-line quality level, which is the threshold that used products must exceed to qualify for remanufacture.

The general in-house versus outsource decision is the subject of a vast amount of study in multiple disciplines, for which Tsay (2014) can serve as an overview. Regarding the decision for remanufacturing in particular, the available research is sparse since the options have been limited. That is, remanufacturing activities have until recently been carried out primarily by small, independent, and privately-owned outside service providers (Guide, 2000). As the volume of remanufacturing has grown, more firms have begun performing these activities in-house or evaluating the ramifications of doing so. Our research informs this possibility directly. Our model of the outsourcing approach assumes the third-party charges the retailer a per-unit

fee for performing the remanufacturing, and controls the decision of how much of the collected used goods to actually remanufacture.

The literature on the environmental impact of remanufacturing is growing (see, for example, Corbett and Kleindorfer, 2001a; and Corbett and Kleindorfer, 2001b). We are able to assess the environmental impact of each strategy choice as measured by the volume of the collected/used products remanufactured since we endogenize the base-line quality level decision for each strategy choice. This allows characterization of key trade-offs. For instance, a low base-line quality level leads to a less environmental harm (as more collected/used products are remanufactured) but also higher costs. Enabling simultaneous consideration of financial and environmental goals aligns with work such as Tang and Zhou (2012), who formulated a "PPP ecosystem" to illuminate the triple-bottom-line objective (profit, people, and planet).

In sum, we draw upon and extend prior research in remanufacturing to examine how a firm evaluates the strategic choice between an in-house remanufacturing channel and an outsourced one. Our analysis integrates a combination of salient factors that has not previously been studied: uncertainty in the quality of product returns; costs and efficiencies specific to each strategy choice; endogenization of the base-line quality level decision which drives the volume of collected/used products that are remanufactured; and cannibalization effects when remanufactured and new products are both available to consumers. The next section describes our analytical framework.

3 Analytical Framework

3.1 Preliminaries

Our stylized reverse supply chain setting for a single product is as follows. A single retailer serves a market by offering a new product (identified by subscript n) as well as a remanufactured version of the same product (identified by subscript r). The new product is procured by the retailer from a supplier at wholesale price w_n and offered to customers at retail price p_n which is pre-specified by the supplier (of course, $p_n > w_n$ and both these prices are assumed to be exogenous). A key decision for the retailer is to determine the remanufactured product price p_r , with a requirement that $p_r < p_n$. All events transpire within a single period.

The product has a specified performance capability when functioning properly, which we call "functional quality." We assume that remanufacturing restores used goods to exactly the functional quality level of the new product, in accord with GameStop's actual practice. To simplify analysis without loss of generality, we normalize this quality level to 1 (i.e., $q_n = q_r = 1$). A consumer derives one of the following two net utility levels from purchasing a new or remanufactured product, respectively:

$$u_n = \gamma q_n - p_n = \gamma - p_n \quad (1)$$

$$u_r = \alpha \gamma q_r - p_r = \alpha \gamma - p_r \quad (2)$$

γ in these utility functions is the consumer's willingness-to-pay and uniformly in the interval $(0,1)$. In equation (2), $\alpha \in (0,1)$ is a constant reflecting consumer perception that the remanufactured product is inferior to the new product quality-wise, which is reminiscent of the term "perceived

quality." Any subsequent use of the term "quality" will refer to functional quality, and perceived quality will always be explicitly labeled as such. A consumer's choice between new and remanufactured products is driven by comparing the net utility levels in equations (1) and (2). This leads to: (a) Case 1: If $\frac{p_r}{\alpha} < p_n$. In this case, the consumers with willingness-to-pay $\gamma \in [\frac{p_r}{\alpha}, \frac{p_n - p_r}{1 - \alpha}]$ prefer to buy a remanufactured product. Those with $\gamma \in [\frac{p_n - p_r}{1 - \alpha}, 1]$ will buy a new product; or (b) Case 2: If $\frac{p_r}{\alpha} \geq p_n$. In this case, all consumers with $\gamma \in [p_n, 1]$ will buy new products while the remainder will buy nothing.

We deemphasize Case 2 for the remainder of the paper since in that setting only the new product would be offered. Then the reverse channel would not exist, obviating the need for any decision between in-house remanufacturing and outsourcing. Focusing on Case 1 with market size normalized to 1 leads to the following demand functions for the two product types:

$$D_n = 1 - \frac{p_n - p_r}{1 - \alpha} \quad (3)$$

$$D_r = \frac{\alpha p_n - p_r}{\alpha(1 - \alpha)} \quad (4)$$

Total market coverage is then $1 - \frac{p_r}{\alpha}$. These demand variables (as well as the various decision variables and performance outcomes) will later be further subscripted with i to indicate dependence on the design of the reverse channel, i.e., whether the retailer remanufactures in-house (identified by a subscript of $i=1$) or outsources the activity to a third-party (a subscript of $i=2$). We refer to the former strategy as "In-house" and the latter as "Outsourcing."

The supply of product available to meet the above demand is denoted by S . S is the amount of collected product available for remanufacturing, which is exogenous to the model and normalized to take a maximum value of 1 ($0 < S \leq 1$). S is the ratio of total collected items to total cumulative sales, with collection activities carried out by the retailer (e.g., GameStop retail stores accepting used game consoles) or a third-party.

The functional quality of a collected item is θ , which is uniformly distributed on the range $(0,1)$ with probability density $f(\theta)$. The fraction of returned products available for remanufacturing for each strategy choice is $\int_0^{\tilde{\theta}_i} f(\theta) d\theta = 1 - \tilde{\theta}_i$, where $\tilde{\theta}_i$ represents the base-line quality level such that all collected items with at least this functional quality will be remanufactured. This endogenously-determined threshold also indicates the proportion of collected products destined for disposal, hence serves as our measure of environmental impact. The "best" environmental outcome is $\tilde{\theta}_i = 0$, i.e., remanufacturing of 100% of collected items. $\tilde{\theta}_i = 1$ (no remanufacturing) is the "worst" outcome.

The two strategies differ in cost. The per-unit cost associated with remanufacturing is a function of effort expended to restore to the quality level of the new product. Given $q_n = q_r = 1$, the per-unit cost of remanufacturing under strategy choice i is defined as $C_i = c_i(1 - \theta)$, where θ is the quality of each collected item ($0 \leq \theta \leq 1$).

The parameter c_i allows the two strategies to differ in their efficiency of remanufacturing. This leads to these expressions of the total expected remanufacturing cost for each strategy:

In-house:

$$\int_{\tilde{\theta}_1}^1 c_1(\theta) S f(\theta) d\theta = \int_{\tilde{\theta}_1}^1 c_1(1 - \theta) S f(\theta) d\theta = \frac{c_1 S (1 - \tilde{\theta}_1)^2}{2} \quad (5)$$

and; Outsourcing:

$$\int_{\tilde{\theta}_2}^1 c_2(\theta) S f(\theta) d\theta = \int_{\tilde{\theta}_2}^1 c_2(1 - \theta) S f(\theta) d\theta = \frac{c_2 S (1 - \tilde{\theta}_2)^2}{2} \quad (6)$$

The next two sub-sections describe our approach for analyzing each strategy.

3.2 In-house Remanufacturing

For this strategy choice the retailer's two decision variables are the price of the remanufactured product (p_r) and the base-line quality level ($\tilde{\theta}_1$) such that all collected items whose incoming quality exceeds $\tilde{\theta}_1$ will be remanufactured. Since the total quantity of collected items is exogenous, the cost of acquiring these goods will be unaffected by the retailer's reverse channel decisions, so we assign this fixed cost a value of zero for the sake of simplicity. Our analysis does not consider the sales of complementary products (such as game software for GameStop) since many retailers of remanufactured goods do not have this kind of product portfolio.

The retailer's total profit is revenue generated from selling new and remanufactured products less the costs of procuring new product and remanufacturing collected items.

This results in the following constrained profit-maximization problem, with the constraint specifying that sales volume of the remanufactured product cannot exceed the total collections:

$$\text{Max}_{0 \leq p_{r1} \leq \alpha p_n, 0 \leq \tilde{\theta}_1 \leq 1} \pi_1 = (p_n - w_n)D_{n1} + p_{r1}D_{r1} - \frac{c_1 S(1 - \tilde{\theta}_1)^2}{2} \quad (7)$$

s.to: c_1

$$D_{r1} \leq S \int_0^{\tilde{\theta}_1} f(\theta) d\theta = S(1 - \tilde{\theta}_1) \quad (8)$$

The constraint in equation (8) always binds at optimality and Table 1 reports the resulting optimum.

Table 1 shows that the solution is driven by c_1 , the remanufacturing efficiency parameter. The following properties hold:

(a) When $c_1 \in (0, x - y]$, the retailer charges a price for the remanufactured product that does not depend on c_1 , and remanufactures all collected products. The total market served by both products will be greater than when only the new product is offered, although retailer profit declines (linearly) with c_1 , in this range. The underlying intuition is that when remanufacturing can be done very efficiently, all collected products will be remanufactured $\tilde{\theta}_1^* = 0$ and put on the market. Given this fixed demand, the retailer's chosen selling price for the remanufactured product and therefore revenue are both invariant to the remanufacturing cost in the given range. Any increase in the cost of remanufacturing reduces the retailer's profit (linearly).

(b) When $c_1 \in (x - y, 1)$, remanufacturing cost increases, the retailer will raise the selling price of remanufactured product and remanufacture less.

The net effect is to decrease demand for the remanufactured product while increasing demand for the new product. As with the efficient case, the retailer cannot avoid a decline in profit when c_1 increases, but here the relationship is non-linear.

Table 1 Optimal solution for In-house remanufacturing
where $x = \alpha w_n$ and $y = 2\alpha(1 - \alpha)S$.

| | Range for c_1 | |
|----------------------|--|---|
| | $c_1 \in (0, x - y]$ | $c_1 \in (x - y, 1]$ |
| p_{r1}^* | $\alpha[p_n - S(1 - \alpha)]$ | $\alpha p_n - \frac{\alpha^2(1 - \alpha)S w_n}{2\alpha(1 - \alpha)S + c_1}$ |
| $\tilde{\theta}_1^*$ | 0 | $1 - \frac{\alpha w_n}{2\alpha(1 - \alpha)S + c_1}$ |
| D_{n1}^* | $1 - p_n - \alpha S$ | $1 - p_n - \frac{\alpha^2 S w_n}{2\alpha(1 - \alpha)S + c_1}$ |
| D_{r1}^* | S | $\frac{\alpha S w_n}{2\alpha(1 - \alpha)S + c_1}$ |
| π_1^* | $(p_n - w_n)(1 - p_n) + \frac{S}{2}[2\alpha w_n - c_1 - 2\alpha(1 - \alpha)S]$ | $(p_n - w_n)(1 - p_n) + \frac{\alpha^2 S w_n^2}{4\alpha(1 - \alpha)S + 2c_1}$ |

3.3 Outsourcing of Remanufacturing

In this strategy a third-party remanufactures the returned items and then the retailer sells these alongside brand-new products (i.e., the reverse supply chain now contains a second decision-maker). We assume that number of collected/used items available for remanufacturing (i.e., S) is the same as for the In-house strategy. As explained in the previous sub-section, the cost of acquiring these items would show up in the retailer's profit function as a fixed cost, so we set this value to zero. The used goods are provided as input materials to the third-party, who remanufactures for a per-unit fee. We refer to this fee as a wholesale price, although it could also be interpreted as a fee for providing the remanufacturing services. This is consistent with standard practices in outsourced manufacturing in general, where an OEM client might directly procure and ship some portion of the raw materials to its contract manufacturer, meaning that the final invoice should net out the cost of these materials.

We analyze this outsourcing approach as a two-player decision problem with the third-party as Stackelberg leader and the retailer as follower. The third-party's decision variables are the per-unit wholesale price for the remanufactured product $w_{r,2}$ and base-line quality level $\tilde{\theta}_2$, while the retailer chooses the remanufactured product's selling price $p_{r,2}$. The third-party sets $w_{r,2}$ to maintain incentive-compatibility for the retailer. All information is common knowledge.

We first characterize the demand for the remanufactured product (D_{r2}) as a function of the w_{r2} faced by the retailer. The retailer's profit-maximization problem is:

$$\text{Max}_{w_{r2} \leq p_{r2}} \pi_2 = (p_n - w_n)D_{n2} + (p_{r2} - w_{r2})D_{r2} \quad (9)$$

where D_{n2} and D_{r2} are as defined earlier in equations (3) and (4). Equation (7) is strictly concave in p_{r2} for a given w_{r2} . The retailer's best-response selling price for the remanufactured product is:

$$p_{r2}(w_{r2}) = \alpha p_n - \frac{(\alpha w_n - w_{r2})}{2} \quad (10)$$

Substituting equation (10) into equation (4) indicates that at a given w_{r2} the demand for the remanufactured product is:

$$D_{r2}(w_{r2}) = \frac{(\alpha w_n - w_{r2})}{2\alpha(1 - \alpha)} \quad (11)$$

We assume that $\alpha w_n - w_{r2} \geq 0$ so that demand for remanufactured product is non-negative. The third-party's profit-maximization problem is then:

$$\text{Max}_{w_{r2} \leq \alpha w_n, 0 \leq \tilde{\theta}_2 \leq 1} \pi_{20} = w_{r2}D_{r2} - \frac{c_2 S(1 - \tilde{\theta}_2)^2}{2} \quad (12)$$

s.to:

$$D_{r2} \leq S \int_0^{\tilde{\theta}_2} f(\theta) d\theta = S(1 - \tilde{\theta}_2) \quad (13)$$

Table 2 shows the resulting Stackelberg equilibrium. Table 2 shows how the equilibrium for the outsourcing option is shaped by c_2 , the third-party's remanufacturing efficiency parameter. The following properties hold:

When $c_2 \in (0, x - 2y]$, the third-party charges a wholesale price for the remanufactured product that does not depend on the cost of remanufacturing, and remanufactures all collected products. The retailer in turn holds fixed the remanufactured product's selling price. Within the stated range of third-party remanufacturing cost, the third-party profit decreases (linearly) with c_2 while the retailer profit is constant. With demand being constant, the retailer's selling price for the remanufactured product is invariant to the remanufacturing cost in the given range. The constant demand for both products and constant product prices makes the third-party profit decline (linearly) as remanufacturing costs increase.

When $c_2 \in (x - 2y, 1)$, remanufacturing costs increase, the third-party remanufactures a smaller quantity and increases the wholesale price. In turn the retailer also increases the remanufactured product's selling price (to cover increases in the wholesale price), which decreases demand for this category. Once again, adding the remanufactured product to the portfolio increases total market coverage. Profits for both the third-party and the retailer decline (non-linearly) as the remanufacturing cost increases.

Table 2 Equilibrium for Outsourcing of remanufacturing
Where $x = \alpha w_n$ and $y = 2\alpha(1 - \alpha)S$.

| | Range for c_2 | |
|----------------------|---|---|
| | $c_2 \in (0, x - 2y]$ | $c_2 \in (x - 2y, 1]$ |
| w_{r2}^* | $\alpha[w_n - 2S(1 - \alpha)]$ | $\alpha w_n - \frac{2S\alpha^2(1 - \alpha)w_n}{4\alpha(1 - \alpha)S + c_2}$ |
| p_{r2}^* | $\alpha[p_n - S(1 - \alpha)]$ | $\alpha p_n - \frac{S\alpha^2(1 - \alpha)w_n}{4\alpha(1 - \alpha)S + c_2}$ |
| $\tilde{\theta}_2^*$ | 0 | $1 - \frac{\alpha w_n}{4\alpha(1 - \alpha)S + c_2}$ |
| D_{n2}^* | $1 - p_n - \alpha S$ | $1 - p_n - \frac{S\alpha^2 w_n}{4\alpha(1 - \alpha)S + c_2}$ |
| D_{r2}^* | S | $\frac{S\alpha w_n}{4\alpha(1 - \alpha)S + c_2}$ |
| π_2^* | $(p_n - w_n)(1 - p_n) + \alpha(1 - \alpha)S^2$ | $\frac{(p_n - w_n)(1 - p_n)}{S^2(1 - \alpha)\alpha^3 w_n^2} + \frac{S^2(1 - \alpha)\alpha^3 w_n^2}{[4\alpha(1 - \alpha)S + c_2]^2}$ |
| π_{2o}^* | $\frac{S}{2}[2\alpha w_n - c_2 - 4\alpha(1 - \alpha)S]$ | $\frac{S\alpha^2 w_n^2}{8\alpha(1 - \alpha)S + 2c_2}$ |

The next section provides structural insights regarding how the retailer should choose between the In-house and Outsourcing strategies.

4 Design of the Reverse Channel for Remanufacturing

This section guides the retailer's decision of whether to remanufacture in-house or outsource to a third-party. Assessment of the two options is with respect to two distinct metrics: retailer profitability and environmental impact. The latter is proxied by the fraction of the collected second-hand product that actually proceeds to remanufacture. The analysis focuses on the remanufacturing efficiency of each strategy choice. What follows will make use of the following ordering of the boundaries of the distinct cases appearing in Tables 1 and 2, which are straightforward consequences of our parameter assumptions: $0 < x - 2y < x - y < 1$.

4.1 Profitability

The following Proposition identifies when each approach to remanufacturing will provide the retailer with superior profits. Figure 1 then presents the findings visually.

Proposition 1: Define $\hat{c} = \frac{x^2 - y^2}{y}$ and $g(c_1) = y(\sqrt{1 + \frac{c_1}{y}} - 2)$ where

$$x = \alpha w_n \text{ and } y = 2\alpha S(1 - \alpha).$$

If $c_1 \in (0, \hat{c}]$, then regardless of the value of c_2 , In-house is more profitable for the retailer;

If $c_1 \in (\hat{c}, 1)$, then: (a) If $c_2 \in (g(c_1), 1)$, In-house is more profitable for the retailer; and (b) If $c_2 \in (0, g(c_1))$, Outsourcing is more profitable for the retailer.

The retailer's decision of whether to outsource remanufacturing incorporates a cost effect and a revenue effect. The cost effect stems from the relative magnitudes of c_1 and c_2 while the revenue effect is tied to increases in sales of the new and/or remanufactured products. When remanufacturing can be conducted cheaply in-house, the cost effect discourages outsourcing even if the third-party can also perform the task at low cost (c_2 is very small). When both parties can remanufacture at low cost, the profit margins are high and so is revenue since all collected items tend to be remanufactured. This makes the retailer reluctant to share the profit with the third-party, as outsourcing would necessitate. When the In-house remanufacturing cost is large, the retailer's decision is driven by the cost differential between the two strategies. As long as c_2 is sufficiently small, the wholesale price will be low and the resulting sales of remanufactured product will make Outsourcing attractive. But as c_2 increases and closes the gap between the two strategies' retail prices for the remanufactured product, in which case the retailer will opt to remanufacture In-house. These findings are on display in Figure 1. The following observation characterizes how the cost parameters impact the price of the remanufactured product and the demand for both products.

Observation 1

1. If $c_1 \in (0, x - y]$ and $c_2 \in (0, x - 2y]$, In-house and Outsourcing strategies are identical in the price of the remanufactured product and the demand for both products.
2. If $c_1 \in (x - y, 1)$ and $c_2 \in (x - 2y, 1)$, the more profitable remanufacturing strategy will be the one for which the remanufactured product has the lower price and the larger demand.

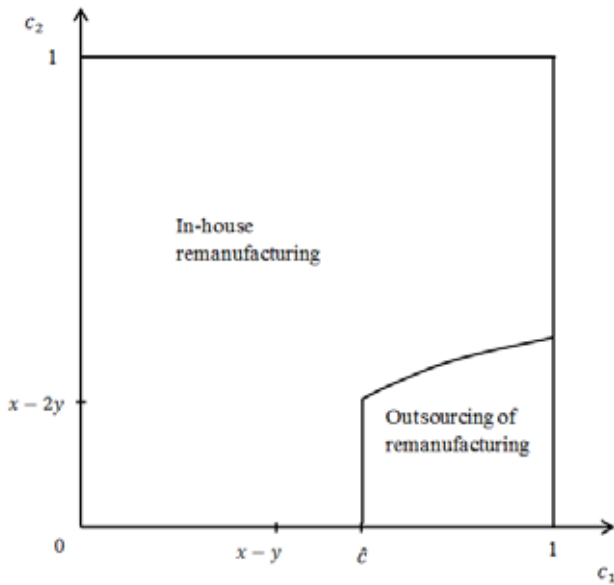


Figure 1 Regions where each strategy is preferred from a profit perspective

We next discuss the strategy choice from an environmental perspective.

4.2 Environmental Impact

Our measure of the environmental impact is $\tilde{\theta}_i$ which represents the fraction of collected items that will not undergo remanufacturing. Lower values are better for the environment. The following Proposition identifies the strategy that is better in this respect, then Figure 2 illustrates the findings.

Proposition 2 : The more environmentally friendly strategy can be identified as follows, with $x = \alpha w_n$ and $y = 2\alpha(1 - \alpha)S$:

If $c_1 \in (0, x - y]$ and $c_2 \in (0, x - 2y]$, both strategies identically achieve the lowest possible environmental impact;

If $c_1 \in (x - y, 1)$ and $c_2 \in (0, x - 2y)$, Outsourcing is superior;

If $c_1 \in (0, x - y]$ and $c_2 \in (x - 2y, 1)$, In-house is superior;

If $c_1 \in (x - y, 1)$ and $c_2 \in (x - 2y, 1)$, then: (a) if $c_1 - c_2 < y$, In-house is superior; (b) if $c_1 - c_2 = y$, both strategies have the same environmental impact; and (c) if $c_1 - c_2 > y$, Outsourcing is superior.

This Proposition and the corresponding Figure 2 show that when both strategies can remanufacture at low cost, all units will be remanufactured. When In-house is relatively higher in cost than Outsourcing, the third-party chooses a lower base-line quality level than the retailer would. This makes Outsourcing the better choice for the environment. When the remanufacturing costs of both strategies are high, the size of the gap between the two costs defines when each strategy will dominate. In-house tends to be the better choice in more of the cases.

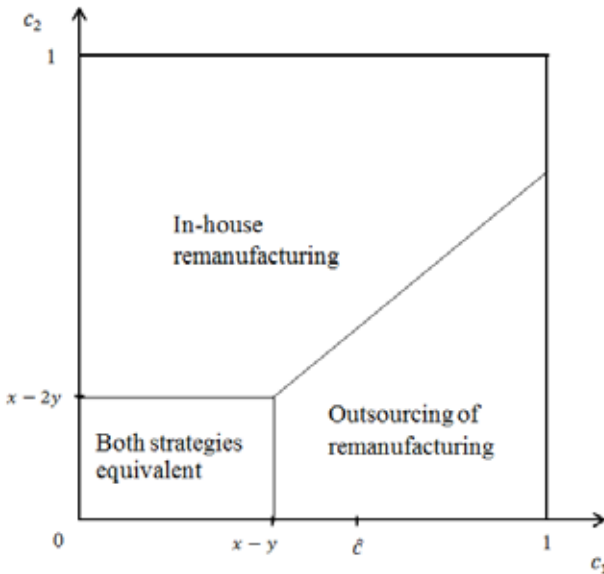


Figure 2 Regions where each strategy is preferred from an environmental perspective

4.3 Joint Consideration of Profit and Environmental Impact

Here we evaluate the extent of incongruence between the retailer's pursuit of profit and concern for the environment. This entails combining the analytical conclusions of Propositions 1 and 2. Figure 3, which overlays Figures 1 and 2, graphically illustrates when the profit and environmental objectives can be achieved with the same remanufacturing strategy, and when the objectives conflict. In this Figure, the labels I, O, P, and E refer to In-

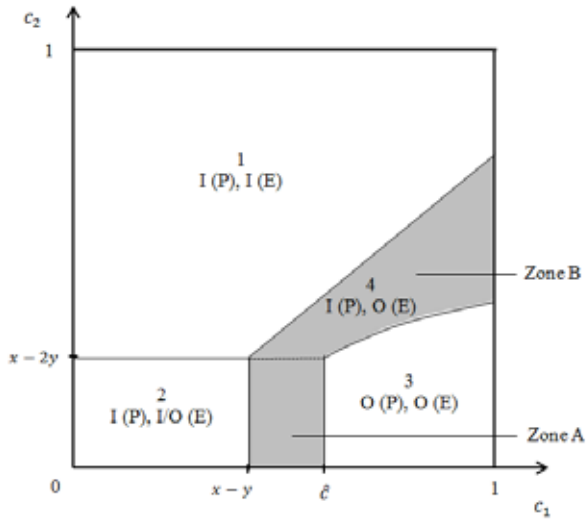


Figure 3 Profit vs environmental impact: region of "conflict"

house, Outsourcing, profitability, and environmental-friendliness, respectively. Then $I(P)$ indicates that In-house remanufacturing is more profitable, $O(E)$ indicates that Outsourcing strategy is more environmentally-friendly, $O/I(E)$ indicates that the environmental impact is the same for both strategies, and so on.

Figure 3 displays four regions. In two of them the retailer can maximize profit and minimize environmental impact simultaneously, by remanufacturing In-house in region 1 and by Outsourcing the remanufacturing in region 3.

Both options have equal environmental impact in region 2, while In-house provides superior profit. Region 4 exhibits "conflict," in that In-house gives greater profit while Outsourcing is better for the environment.

Three of the regions require no special intervention since the profit and environmental objectives can be satisfied simultaneously. "Conflict" occurs in region 4. Based on the conditions in Proposition 3, this region is divided as follows into two parts that reflect the efficiencies at which each party can remanufacture (see Figure 3):

Zone A (efficient remanufacturing): $c_1 \in [x - y, \hat{c}]$ and $c_2 \in (0, x - 2y)$;

and Zone B (inefficient remanufacturing):

$$c_1 \in [x - y, 1] \text{ and } c_2 \in \max \left\{ x - 2y, y \left(\sqrt{1 + \frac{c_1}{y}} - 2 \right), c_1 - y \right\}$$

The next section investigates ways to align the objectives in these two zones.

5 Alignment of Profit and Environmental Goals

This section outlines an approach to aligning the profit and environmental objectives within each of the two zones in the region of "conflict."

In the "conflict" region the retailer maximizes profit by remanufacturing In-house, but Outsourcing would be better for the environment. This section explores whether changing the contract with the third-party to one that shares the third-party's profit can lead the retailer to prefer Outsourcing. This would resolve the conflict if, relative to the In-house decision absent profit-sharing, the equilibrium solution would (a) give the retailer at least as much profit, and (b) assure at least as much remanufacturing.

As a basis for the proposed mechanism, we assume that the retailer offers the third-party the opportunity to remanufacture some of the S used items provided the latter would agree to share a percentage ρ of its profits. Hence, our contract design is viable when the third-party agrees to these terms. Contingent on this, the third-party acts as Stackelberg leader in setting the wholesale price. The third-party's decision problem is:

$$\text{Max}_{w_r^p \geq 0, 0 \leq \tilde{\theta}_2^p \leq 1} \pi_{20}^p = (1 - \rho) \left[w_r^p D_r^p - \frac{c_2 S (1 - \tilde{\theta}_2^p)^2}{2} \right] \quad (14)$$

s.to:

$$D_r^p \leq S \int_0^{\tilde{\theta}_2^p} f(\theta) d\theta = S(1 - \tilde{\theta}_2^p) \quad (15)$$

As in the earlier analysis of Outsourcing, the constraint will bind at optimality. The third-party's wholesale price for the remanufactured good (denoted as w_r^p) must take into account the retailer's best-response decisions that drive the value of D_r .

The retailer's profit-maximization problem is:

$$\begin{aligned} \text{Max}_{w_r^p \leq p_r^p} \pi_2^p &= (p_n - w_n) D_n + (p_r^p - w_r^p) D_r \\ &+ \rho \left[w_r^p D_r - \frac{c_2 S (1 - \tilde{\theta}_2^p)^2}{2} \right] \end{aligned} \quad (16)$$

where $D_n = 1 - \frac{p_n - p_r^p}{1 - \alpha}$ and $D_r = 1 - \frac{\alpha p_n - p_r^p}{\alpha(1 - \alpha)}$. It is straightforward to show that π_2^p is concave in p_r^p . This leads to:

$$p_r^p(w_r^p) = \alpha p_n - \frac{S\alpha(1-\alpha)[\alpha w_n - (1-\varrho)w_r^p]}{2S\alpha(1-\alpha) + \varrho c_2} \quad (17)$$

and consequently,

$$D_r(w_r^p) = \frac{S[\alpha w_n - (1-\varrho)w_r^p]}{2S\alpha(1-\alpha) + \varrho c_2} \quad (18)$$

The incentive-compatible profit-maximization problem for the third-party is then:

$$\begin{aligned} \text{Max}_{w_r^p \geq 0, 0 \leq \tilde{\theta}_2^p \leq 1} \pi_{20}^p = (1-\rho) \left\{ w_r^p \left[\frac{S[\alpha w_n - (1-\rho)w_r^p]}{2S\alpha(1-\alpha) + \rho c_2} \right] \right. \\ \left. - \frac{c_2 S(1-\tilde{\theta}_2^p)^2}{2} \right\} \quad (19) \end{aligned}$$

s.t.:

$$\frac{S[\alpha w_n - (1-\rho)w_r^p]}{2S\alpha(1-\alpha) + \rho c_2} \leq S(1-\tilde{\theta}_2^p) \quad (20)$$

The results of the equilibrium solution for this problem are displayed in Figure 4. It can be seen that the profit-sharing mechanism can resolve the conflict in only part of the conflict region.

Conflict persists in the areas of Figure 4 we label Zones C and D. In both zones, when c_2 is sufficiently lower than c_1 , profit-sharing creates the prospect that the retailer can enhance its profit relative to the the corresponding spot of Zone A of Figure 3. At the same time, the third-party has incentive to raise the wholesale price (w_r^p) to offset the profit-sharing, whereby

the retailer ends up with less profit than under the original in-house strategy. The underlying reason is that the third-party always has an incentive to push up the transfer price after the retailer has decided to outsource the remanufacturing.

The agreement to share its profit induces the third-party to lower the baseline quality threshold for remanufacturing, making the Outsourcing strategy with profit-sharing more environmentally friendly than the original Outsourcing strategy choice. The wholesale price also goes up, raising the possibility that the third-party is not necessarily worse off for entering into the profit-sharing scheme.

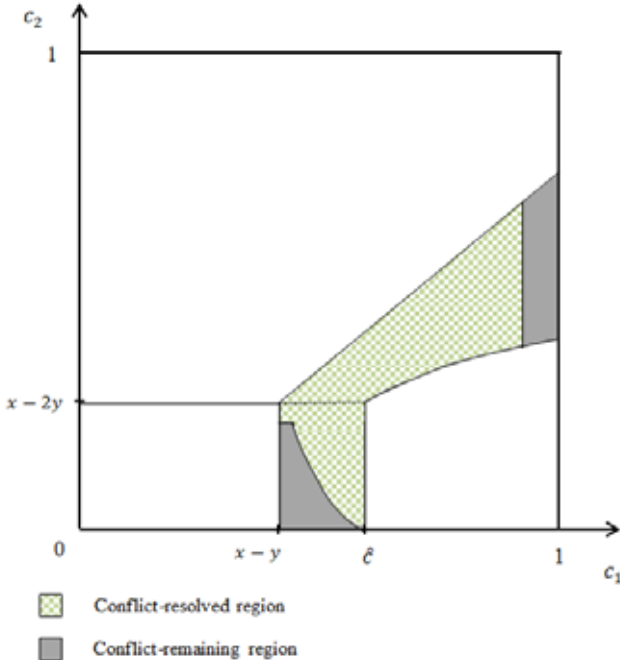


Figure 4 Area where profit-sharing mechanism can resolve conflict

6 Implications and Conclusions

Our research is motivated by the case of GameStop, who initially outsourced the remanufacturing of game consoles then subsequently built this capability internally. We have provided parametric guidelines for making the strategic choice between the In-house and Outsourcing options. We have introduced a metric of the environmental impact of each approach to remanufacturing.

The major contributions and managerial insights stemming from this research are as follows. First, we have analytically determined the optimal/equilibrium selling price of remanufactured product, base-line quality level for remanufacturing, retailer profit, and market shares for new and remanufactured products under each strategy choice. We have identified cases in which the retailer should not remanufacture all of the collected products.

Second, we have found cases where In-house remanufacturing is preferred, even though Outsourcing provides access to more efficient remanufacturing capability. This is because the third-party expects compensation.

Third, we have determined when profit and environmental objectives are at odds. Practitioners should find this particularly useful when faced with public pressure to prioritize environmental protection. To resolve this conflict, we propose a profit-sharing agreement between the third-party remanufacturer and the retailer. For this we show that the Outsourcing can be made to dominate In-house remanufacturing in both retailer profitability and environmental impact. Unfortunately, this approach does not work in all cases of conflict between the two goals.

Future research can examine mechanisms by which the retailer acquires used products and how this moderates the choice of the remanufacturing strategy. For instance, the terms of GameStop's trade-in program impact both the quantity and quality of returned game consoles, which our model has identified as key determinants of the relative desirability of the In-house and Outsourcing approaches. A second issue of interest would be the moderating role of product lifecycle on the choice of the remanufacturing strategy. It is reasonable to hypothesize that Outsourcing might be preferred during the start-up and decline phases, while In-house would outperform in the growth and maturity phases.

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