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Selection of buyback price for OEM for efficient spare parts management in remanufacturing business

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A B S T R A C T

Authors developed a two-period buyback pricing model which shows a competition between independent repair shop, third party remanufacturer (TPR) and original equipment manufacturer (OEM) for market share in spare parts business after the end of warranty period. Remanufacturing is a profitable option for OEM rather than producing new parts after finishing the warranty period for satisfying the demand of spare parts. OEM acquires damaged/broken parts from local independent repair shop to remanufacture those parts. But if there existed any Third Party Remanufacturer (TPR) then it would lead competition and would decrease the market share of OEM in sales of spare parts. TPR is basically independent remanufacturer. OEM has no control over the activity of the TPR for selling remanufactured spare parts after finishing warranty period of the products. In this paper, authors considered a supply chain model, where independent repair shop is responsible for handling the repair process and both OEM and TPR are remanufacturing spare parts. Repair shop may procure spare parts from both OEM and TPR. A discount is given on the price of the spare parts by TPR which attracts the customers. Repair shop also tries to sell repaired parts at an attractive discounted price. Both TPR and OEM need to collect broken/damaged parts to remanufacture them for maintaining an inventory of spare parts. This paper aimed to develop a deterministic framework for finding optimal buyback price for the OEM and the impact of different parameters on the profitability of spare parts management for individual players of supply chain management.

1. Introduction

Spare parts management is significant area of concern for original equipment manufacturers (OEM) manufacturing durable products. According to Inderfurth and Mukherjee (2008) a successful spare parts management depends on the availability of the right type of spare parts in right quality and at quantity at the right time. Kleber et al. (2011) added that OEM has to keep its inventory to make sure to get spare parts during the entire product life cycle (PLC) and also in the post product life cycle (PLC). Manufacturing industries mainly face problem to manage spare parts demand during the time span

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between ends of production (EOP) and ends of service (EOS). Many researchers select product recovery options as the best solution of the spare parts management after EOP of parent product. Hesselbach et al. (2002) suggested that with the used products from disposer market a firm may initiate remanufacturing business of the spare parts. Seitz and Peattie (2002) chose remanufacturing as the only way to meet the customer demand during its useful life in case of automobile engine. Spare parts remanufacturing is profitable in terms of energy saving, raw material saving rather than producing new parts. APRA (Automotive parts remanufacturing association) presented in its report that remanufactured STARTER saves 8.2 million gallons crude oil from steel manufacturing, 51,500 tons of iron ore and 6,000 tons of copper and other metals. As per the study of the Fraunhofer institute in Stuggart Germany, remanufacturing can save energy of equal amount of worldwide electricity produced by the five nuclear power plants or 10,774000 barrels of crude oil which corresponds to fleet of 233 oil tankers in a year. Another important factor of spare parts remanufacturing is environmental concern besides the economic factor of the companies. By remanufacturing, BOSCH reduces CO_2 emissions by 25,000 tons a year compared to newly produced products. BOSCH also experiences material savings of nearly 90% through re-use. CATERPILLAR, remanufactures or recycles 134 million lbs material per year. Well known car manufacturers BMW, FORD, HYUNDAI, TOYOTA, VOLKSWAGEN, and MITSUBISHI etc. involve in product recovery activities for economic and environmental factors. In India, MARUTI SUZUKI (Gurgaon), HONDA INDIA (Noida), BMW (Hyderabad), FORD (Chennai) remanufacture used parts for energy conservation, raw material conservation, landfill space conservation and reducing pollutant values. Profitability of after sales market increases competition between several independent actors in remanufacturing business. Toffel (2003) discussed about the several independent players (parts manufacturer, Original equipment manufacturer, local repair center), who involves in various product recovery activities. In India, besides Original equipment manufacturers (OEM), several local independent remanufacturers like SOFTEX industrial products PVT. LTD. (Kolkata), Apex auctions India PVT. LTD. (Gurgaon), AVN manufacturers (Noida), Bbc India (Delhi), Bohra exports (Mumbai), Emen and sons (Karnataka), Gujrat Forgings LTD. (Rajkot), Jalaram marketing (Rajkot), P.M. trading company (Ahmedabad), Pawan motors (Gurgaon), Hi –Tech engineers (Kolkata) also involve in product recovery activities in the area of automobile sector. Kleber et al. (2011) developed their multistage model based on a case study (gas heating system and boiler manufacturing company) with two actors, OEM and independent repair shop and they further obtained buyback price by developing an analytical model. In the present study, a similar procedure is adopted to develop the two-period buyback pricing model with three players, OEM, TPR and independent repair shop, where we formulated buyback price for the individual actors.

This paper is structured as follows: related literature review is given in section 2, problem associated with product recovery discussed in section 3, section 4 describes the analysis and discussion of the two-period buyback pricing model, section 5 presents numerical example to present the justification of the model and section 6 discusses about the main findings of this model. Finally section 7 draws the main conclusions from this research.

2. Literature review

OEM faces different challenges to maintain the stock of the spare parts for replacing the damaged/broken parts during entire product life cycle (PLC) and also for a certain period of post product life cycle (PLC). Kennedy et al. (2002) discussed in literature review about some challenging factors of spare parts management such as uncertain demand along PLC and along post PLC, multiple item production and obsolescence of those parts which are rarely used. Discussing about the uncertain demand, Hesselbach et al. (2002) also included that there is different pattern of the time variability of spare parts demand along PLC and along post PLC. Kalchschmidt et al. (2003) discussed about the relationship of spare parts management with the multi echelons supply chain comprising multi modal operations. As a product has different parts, a good spare parts management has to assure the availability of all the parts after ending the servicing period along the PLC and post PLC. So an efficient maintenance of multiple item inventories is one of the areas of concern for the OEM. Firstly Sherbrooke (1968) introduced a systematically method instead of an item approach for simplifying the recoverable item control to sort out the multiple item production problem. Thonemann et al. (2002) improved this systematically approach by introducing an analytical model. Hesselbach et al. (2002) discussed about the obsolescence of the rarely needed parts. According to Hesselbach et al. (2002) this type of complexity of the spare parts management can be solved by producing or procuring of new parts or recovering the used parts through product recovery options. Inderfurth and Mukherjee (2008) developed a decision making model to make an efficient spare part management process through these three available options- (i) producing additional parts at the end of the EOP of the parent product, (ii) extra production/ procurement of parts of the parent product and (iii) remanufacturing of spare parts. Remanufacturing of the damaged parts arise a competition between the different players at the different stages of the supply chain. Toffel (2003) mentioned about various independent players such as parts manufacturer, OEM and repair centre who may perform different product recovery activities by cooperating or competing each other. Majumder and Groenevelt (2001) discussed about the capability of the procurement of recoverable used parts between the OEM and local remanufacturers. Procurement of the damaged/broken parts for using as the resource of the remanufacturing process is the current issue and many researchers like Heese et al. (2005), Deneijer and Flapper (2005), Ray et al. (2005), and Kleber et al. (2011) introduced some model to acquire the damaged parts from the consumers. Heese et al. (2005) presented a model to evaluate the profitability of take back policy of an OEM who sells refurbished products. Similarly, Ray et al. (2005) examined the optimal pricing/trade-in rebate strategies for durable remanufacturable products to identify the main issues that motivate customers to give back products and Deneijer and Flapper (2005) identified the business issues that encourage the OEM to take back the parts resulting from repair activities. Inderfurth and Kleber (2010) proposed a heuristic procedure for multi option spare parts procurement problem.

This present work carries out the profitability of an acquisition of damaged/broken parts from the independent repair shops and moreover trying to stop uncontrolled repair and remanufacture too. Additionally, the results help to determine appropriate buyback price under different situations.

3. Problem Definition

Kleber et al. (2009) presented their multistage model based on a case study (gas heating system and boiler manufacturing company) with two actors, OEM and independent repair shop and they further determined buyback price by developing an analytical model. In the present study, a similar procedure is adopted to develop the two-period buyback pricing model with three players, OEM, TPR and independent repair shop, where we formulated buyback price for the individual actors. Cash flow of each of the players are computed separately for each period as given below. Further, the total cash flow is found by summing for all the periods, i.e., period 1 and 2.

Authors have developed a two-period buyback pricing model with period index, $t = 1,2$. For the period, $t = 1$, the following activities are incorporated in the model.On product failure customers approach the local repair shop for repairing. Repair shop inspects the failed product. If the product requires repairing, the repair shop returns the product to the customer after repairing the damaged/broken parts. If the product requires replacement of damaged/broken parts; the repair shop procures the new parts from the OEM. OEM may prefer to remanufacture used parts rather than producing new parts after the warranty period. TPR present in the market is also interested to sell the remanufactured parts. The damaged/broken parts or products are left in the repair shop is the only source of raw material for remanufacturing .TPR provides repairing services through its own repairing centre (dependent repair shop) to collect damaged/broken parts at free of cost. TPR needs to collect more damaged/broken parts to fulfil the demand for remanufactured parts of both dependent and independent repair shops. Independent repair shop identifies these repairable parts from damaged/

broken parts. Remaining damaged/broken parts at independent repair shop are procured by OEM and TPR, at given buyback price(s). For the period, $t = 2$, demand for new/remanufactured parts generated is fulfilled by repair shop using repaired parts and remaining demand for remanufactured parts is fulfilled by OEM and TPR. OEM and TPR try to collect maximum amount of damaged/broken parts from the repair shop by offering attractive buyback price(s). Figure 1, depicts the conceptual model for various recovery activities considered in this model.
The following activities of repair shops, TPR and OEM are considered in the model.

- In the first period, let d_1^I the total demand for new parts. Initially as there is no stock of spare parts, repair shop will procure new parts from the OEM.
- d_1^I is the amount of damaged/broken parts or products left in the repair shop.
- After inspection of the left over parts, repair shop could repair y^r amount and is kept in its inventory of repaired parts, while the remaining $(d_1 - y^r)$amount is either sold to the recycler at unit revenue of s or sold to the TPR/OEM at a certain buyback price.
- Customers pay p_x per unit for new/remanufactured parts from the OEM but αp_x to TPR.
- In the first period, TPR does not produce remanufacturing items. It satisfies demand d_1^d comes from its own collection centre (dependent repair shop) buying new parts from the OEM at γp_x per unit.
- TPR also collects damaged/broken parts from dependent repair shop and fulfils the first period demand of new parts by procuring from the OEM.
- The repair shop tries to fulfil the demand for the spare parts d_2^I from its inventory of repaired parts,y^r. The remaining demand for the spare parts is $(d_2^I - y^r)$, from which repair shop procures $x_2^s = \zeta(d_2^I - y^r)$ amount from OEM and $x_2^T = (1 - \zeta)(d_2^I - y^r)$amount from the TPR.
- In the second period TPR satisfies demand for remanufactured parts of customers at unit price αp_x through dependent repair shop and satisfies demand for remanufactured parts of independent repair shop at unit price $\gamma\theta p_x$.
- Independent repair shop procures at unit price of γp_x from OEM, where, $\gamma p_x < p_x$ and, a unit price of $\gamma\theta p_x$ from TPR, where $\gamma\theta p_x < \alpha p_x$.

$t =$ Period index with $t = 1,..2$
d_t^I= Deterministic demand at independent repair shop in period $t = 1,..2$
d_t^d= Deterministic demand at dependent repair shop in period $t = 1,..2$
$\zeta =$ Fraction of demand for new parts at independent repair shop
α= Price sensitivity for remanufactured parts from TPR ordered by customers.
p_x= Unit price paid by the customer for new/remanufactured parts from OEM
αp_x= Unit price paid by the customer for remanufactured parts from TPR
β= Price sensitivity for repaired parts from independent repair shop ordered by customers.
$\alpha\beta p_x$= Unit price paid by the customer for repaired parts from independent repair shop
γ= Price sensitivity for new/remanufactured parts from OEM ordered by independent repair shop and TPR.
γp_x= Unit price paid by independent repair shop and TPR for new/remanufactured parts from OEM.
θ= Price sensitivity for remanufactured parts from TPR ordered by independent repair shop.
$\gamma\theta p_x$= Unit price paid by the independent repair shop for remanufactured parts from TPR.
c_p^o= Unit production cost of OEM for producing new parts.
c_r^o= Unit remanufacturing cost of OEM
c_r^r= Unit repairing cost of independent repair shop
c_r^T= Unit remanufacturing cost of TPR.
s= Unit salvage revenue earned for unused items

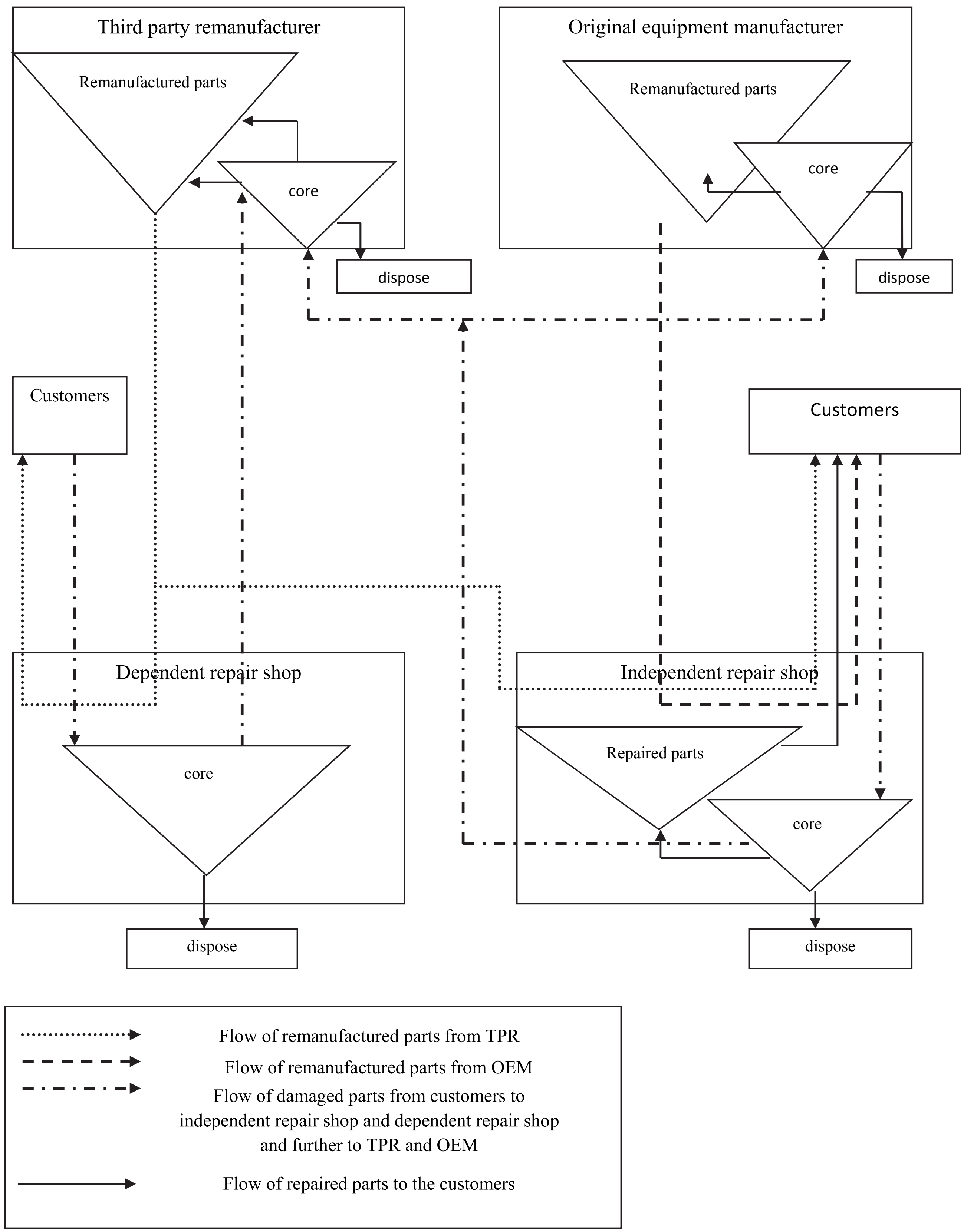

Fig. 1. Conceptual frame work of forward and reverse flow of spare parts for OEM, TPR and independent repair shop

3.2 Decision variables

y^r= Parts repaired by the independent repair shop in the first period.

y^o= Parts remanufactured by the OEM in the first period.

y^T= Parts remanufactured by the TPR in the first period.

x^b= parts sent back by the independent repair shop to the OEM/TPR in the first period.

x_d^b= Parts sent back by the dependent repair shop to the TPR in the first period.

x^d= Parts disposed by the independent repair shop in first period.

x_t^s= Parts procured by the independent repair shop from OEM in period $t = 1,..2$

x_t^T = Parts procured by the independent repair shop from TPR in period $t = 1,..2$

x_t^{sT} = Parts procured by the TPR from OEM in period $t = 1,..2$

p_b= Unit buyback OEM pays for broken parts sent back from independent repair shops.

p_b^T= Unit buyback price TPR pays for broken parts sent back from independent repair shops.

4. Development of the model

4.1 Period 1

Alternatives available for repair shop in period 1 according to Kleber et al. (2009)

- Repair the parts$y^r \leq d_1$at total cost of $c_r^r . y^r$
- Remaining $(d_1 - y^r)$ is either sold to the recyclers or to the supplier/OEM/TPR.

Based on the salvage revenue and buyback price, repair shop makes choices among three alternatives, i.e.

$$(x^b, x^d) = \begin{cases} (d_1^I - y^r), 0; if\ p_b > max(s, p_b^T); sold\ to\ the\ OEM \\ (d_1^I - y^r), 0; if\ p_b^T > max(s, p_b); sold\ to\ the\ TPR \\ 0, (d_1^I - y^r); if\ s > max(p_b, p_b^T); sold\ to\ the\ recyclers \end{cases} \quad (1)$$

Thus, the cash flow of the repair shop at the end of the first period is given by,

$$CF_1^I = (p_x - \gamma p_x)d_1^I + \max\{p_b, p_b^T, s\}\,(d_1^I - y^r) - y^r c_r^r, \text{ where } y^r \leq d_1^I \quad (2)$$

TPR provides repairing service through dependent repair shop. TPR faces competition with OEM to collect damaged/broken parts from local independent repair shop. TPR only can access those damaged parts which are collected from dependent repair shop at free of cost. But for more production of remanufactured parts, TPR requires more damaged/broken parts. For this reason, TPR offers unit buyback price of p_b^T to independent repair shop to collect damaged/ broken parts. In the first period TPR faces demand d_1^d from dependent repair shop for new parts but does not face demand for remanufactured parts from independent repair shop. As there is no remanufactured parts are available at TPR in the first period, demands are fulfilled by procuring new parts from the OEM at unit price of γp_x.

Thus, cash inflow of the TPR in the first period is given by,

$$CF_1^T = (p_x - \gamma p_x)d_1^d - p_b^T x^b - y^T c_r^T + s(x^b + x_d^b - y^T) \tag{3}$$
subject to
$$y^T \le (d_1^d + d_1^I) \tag{4}$$
$$x_d^b = d_1^d \tag{5}$$
$$x^b \le d_1^I \tag{6}$$

Constraint (4) presents amount of remanufactured parts. It should be less than or equal to total quantity of returned parts from both dependent and independent repair shops. Constraint (5) represents that dependent repair shop sends all damaged/broken parts to TPR. Constraint (6) represents that independent repair shop sends less than or equal amount of damaged parts to the TPR.

In the first period OEM faces demand of the new parts from both independent repair shop and TPR. OEM fulfils demand by producing new parts at unit price of c_p^o.OEM collects damaged/broken parts from local independent repair shop at unit price of p_b. Cash inflow of the OEM in the first period is given by,

$$CF_1^o = (\gamma p_x - c_p^o)(d_1^I + d_2^d) - p_b x^b - c_r^o y^o + s(x^b - y^o) \tag{7}$$
subject to
$$y^o \le x^b \tag{8}$$
$$x^b \le d_1^I \tag{9}$$

Constraint (8) presents amount of remanufactured parts. It should be less than or equal to damaged/broken parts which are collected from independent repair shop.

4.2 Period 2

In the second period, independent repair shop tries to fulfil the demand of the spare parts d_2^I from its inventory of repaired parts y^r which yields cash inflow of $\alpha\beta p_x min\{y^r, d_2^I\}$. Thus cash flow of the independent repair shop in the second period is given by,

$$CF_2^I = \alpha\beta p_x min\{y^r, d_2^I\} + (p_x - \gamma p_x)\zeta(d_2^I - y^r) + (\alpha p_x - \gamma\theta p_x)(1-\zeta)(d_2^I - y^r) + s(y^r - d_2^I) \tag{10}$$

TPR tries to fulfil the demand of spare parts $(x_2^T + d_2^d)$ from its inventory of remanufactured parts. Cash flow of the TPR in the second period is given by,

$$CF_2^T = \alpha p_x d_2^d + \gamma\theta x_2^T + s[y^T - \{d_2^d + x_2^T\}] \tag{11}$$
subject to
$$y^T \ge \{d_2^d + (x_2^T)\} \tag{12}$$
$$x_2^T \le d_2^I \tag{13}$$

OEM tries to fulfil the demand of spare parts $x_2^s = \zeta(d_2^I - y^r)$ from its inventory of remanufactured parts. For excess demand it will produce new parts. Cash flow of the OEM in the second period is given by

$$CF_2^o = \gamma p_x x_2^s - c_p^o[x_2^s - y^o] + s[y^o - x_2^s] \tag{13}$$

For the ease of computational purpose, authors first tried to determine the optimal buyback price of the TPR and then based on the buyback price of the TPR the optimal buyback price of the OEM is computed.

4.3 Optimal strategies of independent repair shop

Combining Eq. (2) and Eq. (10), the optimum profit for the independent repair shop is obtained as,

$$\max\pi^{IR} = (p_x - \gamma p_x)d_1^I + max\{p_b, p_b^T, s\}(d_1^I - y^r) - y^r c_r^r + \alpha\beta p_x min\{y^r, d_2^I\} + (p_x - \gamma p_x)\zeta(d_2^I - y^r) + (\alpha p_x - \gamma\theta p_x)(1-\zeta)(d_2^I - y^r) + s(y^r - d_2^I) \quad (14)$$

subject to

$$0 \le y^r \le d_2^I \quad (15)$$

For deterministic demand, the independent repair shop will not repair quantity more than the second period's demand i.e. $d_2^I \ge y^r$. The additional unit profit from the repaired parts for repair shop is obtained from expression (14), as

$$\pi = (\alpha\beta p_x - c_r^r) - p_x(1-\gamma)\zeta - p_x(\alpha - \gamma\theta)(1-\zeta) \quad (16)$$

So Eq. (14) becomes,

$$\max\pi^{IR} = p_x(1-\gamma)(d_1^I + \zeta d_2^I) + p_x(\alpha - \gamma\theta)(1-\zeta)d_2^I + max\{p_b, p_b^T, s\}d_1^I + [\pi - max\{p_b, p_b^T, s\}]y^r \quad (17)$$

If the term $[\pi - max\{p_b, p_b^T, s\}]y^r$ in Eq. (17) becomes positive then repair will take place at the maximum possible level. Otherwise repair shop will prefer to sell all the damaged parts to the recycler or to the TPR/OEM. Repair shop selects repairing quantity y^r which is less than or equal amount of damaged parts left at the repair shop d_1^I in the first period and less than or equal amount of demand for the new parts in the second period i.e. d_2^I.

$$y^r = \begin{cases} min(d_1^I, d_2^I); if\ \pi > \max(p_b, p_b^T, s) \\ \quad 0; \qquad otherwise \end{cases} \quad (18)$$

Salvage revenue, buyback price and additional profit help repair shop to decide about cores. Table 1 shows optimal policy structure for repair shop.

Table 1
Optimal strategies of independent repair shop

Cases and conditions	x^b	x^d	y^r	x_2^s	x_2^T
Case1: $max(p_b, p_b^T, \pi) < s$	0	d_1^I	0	ζd_2^I	$(1-\zeta)d_2^I$
Case 2: $(p_b, p_b^T) \le s < \pi$	0	$(d_1^I - d_2^I)^+$	$min\{d_1^I, d_2^I\}$	$\zeta(d_2^I - y^r)$	$(1-\zeta)(d_2^I - y^r)$
Case 3: $s, p_b^T \le p_b < \pi$	$(d_1^I - d_2^I)^+$	0	$min\{d_1^I, d_2^I\}$	$\zeta(d_2^I - y^r)$	$(1-\zeta)(d_2^I - y^r)$
Case 4: $s, p_b \le p_b^T < \pi$	$(d_1^I - d_2^I)^+$	0	$min\{d_1^I, d_2^I\}$	$\zeta(d_2^I - y^r)$	$(1-\zeta)(d_2^I - y^r)$
Case 5: $p_b > max(p_b^T, s, \pi)$	d_1^I	0	0	ζd_2^I	$(1-\zeta)d_2^I$
Case 6: $p_b^T > max(p_b, s, \pi)$	d_2^I	0	0	ζd_2^I	$(1-\zeta)d_2^I$

In case 1, when salvage revenue is more profitable than all available options, damaged/broken parts are sold to the recyclers and second period's demand is fulfilled by procuring new/remanufactured parts from OEM and TPR. For case 2, when profit earned by selling repaired parts exceeds all other options and salvage revenue is larger than buyback prices of OEM and TPR, repair will take place at the maximum possible level and after satisfying the second period's demand with repaired parts remaining demands are fulfilled by TPR and OEM. If the cores available in the first period are larger than actually required in the second period then excess cores are sold to the recyclers. In case 3, when buyback price of the OEM exceeds both buyback price of TPR and salvage revenue, but does not exceed unit profit of repair shop, excess cores which are not used for repairing are sold to the OEM. Similarly, for case 4, if buyback price of TPR exceeds both salvage revenue and buyback price of OEM but does not exceed unit profit of repair shop; un-repairable parts are sold to the TPR. In case 5, when buyback price of OEM exceeds all options, then all the cores are sold to the OEM. In case 6, when buyback price of TPR exceeds all options, all cores are sold to the TPR.

Based on optimal strategies of independent repair shop, TPR and OEM decide their buyback price (s).

4.4 Comparison of optimal responses of TPR and OEM

4.4.1 Optimal profit expression of TPR

Subsuming and rearranging Eq. (3) and Eq. (11), authors identify the optimal profit for the TPR as given by,

$$\max\pi^T = (p_x - \gamma p_x)d_1^d - p_b^T x^b - y^T c_r^T + s\left(x^b + x_b^d - y^T\right) + \alpha p_x d_2^d + \gamma\theta p_x(1 - \zeta)(d_2^I - y^r) + s[y^T - \{d_2^d + (1-\zeta)(d_2^I - y^r)\}] \text{ Where,} y^T = min\{d_1^d + d_1^I, d_2^d + d_2^I\} \tag{19}$$

The optimal profit of TPR varies with optimal strategies of the independent repair shop.

$(i) case$ 1: $max(p_b, p_b^T, \pi) < s$:

Under this condition, buyback from independent repair shop is not possible, i.e. $x^b = 0$; but TPR collects damaged parts from the dependent repair shop also i.e.$x_d^b = d_1^d$.TPR is able to remanufacture the damaged/broken parts i.e. $y^T = d_1^d$.Total demand from both dependent and independent repair shop is $d_2^d + (1-\zeta)d_2^I$.

The optimal profit of TPR Eq. (19) is given by,

For $d_1^d \le d_2^d$ *and* $d_1^I \le d_2^I$

$$\max\pi_{1a}^T = (p_x - \gamma p_x)d_1^d - d_1^d c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + sd_1^d - sd_2^d - s(1-\zeta) \tag{20}$$

For, $d_1^d > d_2^d$ *and* $d_1^I > d_2^I$

$$\max\pi_{1b}^T = (p_x - \gamma p_x)d_1^d - d_2^d c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + s(1-\zeta)d_2^I \tag{21}$$

$(ii) case$ 2: $(p_b, p_b^T) \le s < \pi$:

Buyback is not possible from independent repair shop i.e., $x^b = 0$. Dependent repair shop returns $x_d^b = d_1^d$ cores to the TPR. TPR faces total demand $d_2^d + (1-\zeta)(d_2^I - y^r)$ and fulfils the demand by remanufactured parts $y^T = d_1^d$; the optimal profit expression of TPR Eq. (19) is given by,

For $d_1^d \le d_2^d$ *and* $d_1^I \le d_2^I$

$$\max\pi_{2a}^{T} = (p_x - \gamma p_x)d_1^d - d_1^d c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)(d_2^I - d_1^I) + s[d_1^d - \{d_2^d + (1-\zeta)(d_2^I - d_1^I)\}] \quad (22)$$

For, $d_1^d > d_2^d \ and \ d_1^I > d_2^I$

$$\max\pi_{2b}^{T} = (p_x - \gamma p_x)d_1^d - d_2^d c_r^T + s(d_1^d - d_2^d) + \alpha p_x d_2^d \quad (23)$$

$(iii) case\ 4$: $s, p_b \le p_b^T < \pi$:

TPR collects $x^b = (d_1^I - d_2^I)^+$ amount of damaged/broken parts from independent repair shop. Independent repair shop procures $x_2^T = (1-\zeta)(d_2^I - d_1^I)$ amount of remanufactured parts from TPR. As $(d_1^I - d_2^I)^+$ and $(d_2^I - d_1^I)$ opposes each other for increasing and decreasing demand, TPR would not consider the cores which are returned from the independent repair shop for remanufacturing. Thus, remanufacturing only would take place with $x_d^b = d_1^I$. The optimal profit of TPR eq. (19) is given by,

For $d_1^d \le d_2^d \ and \ d_1^I \le d_2^I$

$$\max\pi_{4a}^{T} = (p_x - \gamma p_x)d_1^d - p_b^T(d_1^I - d_2^I)^+ - d_1^d c_r^T + s\{(d_1^I - d_2^I)\} + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)(d_2^I - d_1^I) + s[d_1^d - \{d_2^d + (1-\zeta)(d_2^I - d_1^I)\}] \quad (24)$$

For, $d_1^d > d_2^d \ and \ d_1^I > d_2^I$

$$\max\pi_{4a}^{T} = (p_x - \gamma p_x)d_1^d - p_b^T(d_1^I - d_2^I)^+ - d_2^d c_r^T + s\{(d_1^I - d_2^I) + d_1^d - d_2^d\} + \alpha p_x d_2^d \quad (25)$$

$(iv) case6$: $p_b^T > max(p_b, s, \pi)$:

Independent repair shop sells all damaged/broken parts $x^b = d_1^I$to the TPR. Dependent repair shop returns damaged parts to the TPR, i.e., $x_d^b = d_1^d$. For increasing demand ($d_1^I \le d_2^I; d_1^d \le d_2^d$), remanufactured parts is $y^T = d_1^I + d_1^d$. The optimal profit of TPR Eq. (19) is given by,

$$\max\pi_{6a}^{T} = (p_x - \gamma p_x)d_1^d - p_b^T d_1^I - (d_1^d + d_1^I)c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + s[(d_1^d + d_1^I) - \{d_2^d + (1-\zeta)d_2^I\}] \quad (26)$$

For decreasing demand i.e. $(d_1^I > d_2^I; d_1^d > d_2^d)$, remanufactured quantity is $y^T = d_2^I + d_2^d$, then profit expression (19) of TPR is given by,

$$\max\pi_{6b}^{T} = (p_x - \gamma p_x)d_1^d - p_b^T d_1^I - (d_2^d + d_2^I)c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + s[(d_2^d + d_2^I) - \{d_2^d + (1-\zeta)d_2^I\}] \quad (27)$$

4.4.2 Optimal profit expression of OEM

Subsuming and rearranging Eq. (7) and Eq. (13), authors selected the optimal profit expression of OEM as given by,

$$\max\pi^{o} = (\gamma p_x - c_p^o)(d_1^I + d_1^d) - p_b x^b - c_r^o y^o + s(x^b - y^o) + \gamma p_x x_2^s - c_p^o[x_2^s - y^o] + s[y^o - x_2^s] \quad (28)$$

OEM will not remanufacture quantity more than second period's demand, i.e. $y^o \le x_2^s$; the optimal profit of OEM Eq. (28) is given by,

$$\max\pi^{o} = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + x_2^s] - x^b(p_b - s) + y^o(c_p^o - c_r^o - s)] \quad (29)$$

If, Kleber et al. (2009) defines $(c_p^o - c_r^o - s) > 0$ as positive remanufacturing decision for OEM otherwise$(c_p^o - c_r^o - s) \le 0$, it would be more profitable to produce new parts rather than remanufacture damage parts.

The optimal profit of OEM changes with optimal strategies of independent repair shop.

(i) Case 1: $(max(p_b, p_b^T, \pi) < s)$:

Under this condition buyback is not possible, i.e. $x^b = 0$. OEM produces new parts to fulfil second period's demand$(x_2^s = \zeta d_2^I)$. Optimal profit of the OEM is given by,

$$\pi_1^o = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta d_2^I] \tag{30}$$

(ii)Case 2: $(p_b, p_b^T \leq s < \pi)$:

Buyback is not possible i.e.$x^b = 0$. Remanufacturing does not take place, i.e. $y^o = 0$. OEM produces new parts to fulfil the second period's demand, i.e. $x_2^s = \zeta(d_2^I - d_1^I)$. Optimal profit of OEM is given by,

$$\pi_2^o = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I - d_1^I)] \tag{31}$$

(iii)Case 3:$(p_b^T, s) \leq p_b < \pi$:

Independent repair shop sells damaged/broken parts $x^b = (d_1^I - d_2^I)^+$ to the OEM. Independent repair shop procures new/remanufactured parts $x_2^s = \zeta(d_2^I - d_1^I)^+$ from the OEM. Quantity of damaged parts which are collected in the first period and second period's demand for new/remanufactured parts opposes each other for increasing or decreasing demand. Thus OEM does not remanufacture damaged/broken parts i.e. $y^o = 0$. Optimal profit Eq. (29) is given by,

$$\pi_3^o = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I - d_1^I)] - (d_1^I - d_2^I)^+(p_b - s) \tag{32}$$

(iv)Case 5: $p_b > max\{p_b^T, s, \pi\}$:

Independent repair shop sells all damaged/broken parts $x^b = d_1^I$ to the OEM. If the profit from remanufacturing is $(c_p^o - c_r^o - s) \leq 0$, then remanufacturing would not take place i.e. $y^o = 0$. Then optimal profit Eq. (29) is given by,

$$\pi_5^o = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I)] - d_1^I(p_b - s) \tag{33}$$

If the profit from remanufacturing is $(c_p^o - c_r^o - s) > 0$, then remanufacturing would take place at its maximum possible level.

For, increasing demand i.e. $d_1^I \leq d_2^I$, remanufacturing quantity is $y^o = d_1^I$

$$\pi_{5a}^o = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I)] - d_1^I(p_b - s) + d_1^I(c_p^o - c_r^o - s) \tag{34}$$
subject to
$$d_1^I \leq \zeta d_2^I$$

For, decreasing demand i.e. $d_1^I > d_2^I$, remanufacturing quantity is $y^o = d_2^I$

$$\pi_{5b}^o = (\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I)] - d_1^I(p_b - s) + \zeta d_2^I(c_p^o - c_r^o - s)$$
subject to
$$d_1^I > \zeta d_2^I \tag{35}$$

Optimal profit expressions of TPR and OEM change according to the optimal strategies of the independent repair shop as given in Table 2.

Table 2

Optimal profit expressions of TPR, supplier and OEM

Cases and conditions		DEMAND	AMOUNT OF REMANUFACTURED PARTS	OPTIMAL PROFIT
Case1: $max(p_b, p_b^T, \pi) < s$	TPR	Increasing	d_1^d	$(p_x - \gamma p_x)d_1^d - d_1^d c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + sd_1^d - sd_2^d - s(1-\zeta)d_2^I$
		decreasing	d_2^d	$(p_x - \gamma p_x)d_1^d - d_2^d c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + s(1-\zeta)d_2^I$
	OEM	Increasing/ decreasing	0	$(\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta d_2^I]$
Case 2: $(p_b, p_b^T) \le s < \pi$	TPR	Increasing	d_1^d	$(p_x - \gamma p_x)d_1^d - d_1^d c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)(d_2^I - d_1^I) + s[d_1^d - \{d_2^d + (1-\zeta)(d_2^I - d_1^I)\}]$
		Decreasing	d_2^d	$(p_x - \gamma p_x)d_1^d - d_2^d c_r^T + s(d_1^d - d_2^d) + \alpha p_x d_2^d$
	OEM	Increasing/decreasing	0	$(\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I - d_1^I)]$
Case 3: $s, p_b^T \le p_b < \pi$	TPR	-	-	-
	OEM	Increasing/decreasing	0	$(\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I - d_1^I)] - (d_1^I - d_2^I)^+(p_b - s)$
Case 4: $s, p_b \le p_b^T < \pi$	TPR	Increasing	d_1^d	$(p_x - \gamma p_x)d_1^d - p_b^T(d_1^I - d_2^I)^+ - d_1^d c_r^T + s\{(d_1^I - d_2^I)\} + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)(d_2^I - d_1^I) + s[d_1^d - \{d_2^d + (1-\zeta)(d_2^I - d_1^I)\}]$
		decreasing	d_2^d	$(p_x - \gamma p_x)d_1^d - p_b^T(d_1^I - d_2^I)^+ - d_2^d c_r^T + s\{(d_1^I - d_2^I) + d_1^d - d_2^d\} + \alpha p_x d_2^d$
	OEM	-	-	-
Case 5: $p_b > max(p_b^T, s, \pi)$	TPR	-	-	-
	OEM	Increasing	d_1^I	$(\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I)] - d_1^I(p_b - s) + d_1^I(c_p^o - c_r^o - s)$
		decreasing	d_2^I	$(\gamma p_x - c_p^o)[(d_1^I + d_1^d) + \zeta(d_2^I)] - d_1^I(p_b - s) + \zeta d_2^I(c_p^o - c_r^o - s)$
Case 6: $p_b^T > max(p_b, s, \pi)$	TPR	Increasing	$d_1^I + d_1^d$	$(p_x - \gamma p_x)d_1^d - p_b^T d_1^I - (d_1^d + d_1^I)c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + s[(d_1^d + d_1^I) - \{d_2^d + (1-\zeta)d_2^I\}]$
		Decreasing	$d_2^I + d_2^d$	$(p_x - \gamma p_x)d_1^d - p_b^T d_1^I - (d_2^d + d_2^I)c_r^T + \alpha p_x d_2^d + \gamma\theta p_x(1-\zeta)d_2^I + s[(d_2^d + d_2^I) - \{d_2^d + (1-\zeta)d_2^I\}]$
	OEM	-	-	-

TPR and OEM select their buyback price (s) depending on the relationship between salvage revenue (s) of the repair shop earned by recycling the damaged/broken parts and unit profit (π) of the independent repair shop earned by selling repaired parts to the customers.

4.5 Optimal profit of TPR varies depending on the relationship of salvage revenue and additional unit profit of independent repair shop

When $\pi < s$:

Under this optimal setting of independent repair shop, Case 1 ($\max(p_b, p_b^T, \pi) < s$) is only considered. TPR can prevent independent repair shop to repair and recycle the damaged parts when $p_b^T > \max(p_b, \pi, s)$.It is clear that for Case 6, it is possible that salvage revenue is larger than unit profit of the independent repair shop. The optimal profit of TPR under optimal setting $\pi < s$ is obtained by,

For increasing demand, $d_1^d \le d_2^d, d_1^I \le d_2^I$

$$\pi_{6a}^T - \pi_{1a}^T = d_1^I(s - p_b^T - c_r^T) \tag{36}$$

For decreasing demand, $d_1^d > d_2^d, d_1^I > d_2^I$

$$\pi_{6b}^T - \pi_{1b}^T = -p_b^T d_1^I + (s - c_r^T)d_2^I \tag{37}$$

In such case, buyback price p_b^T should be larger than salvage revenue to encourage independent repair shop for selling the damaged/broken parts. For increasing and decreasing demand the optimal profit of TPR becomes negative. It represents that Case 1 dominates case 6. It is more profitable for TPR to collect damaged/broken parts from the dependent repair shop for optimal setting $\pi < s$ instead of independent repair shop.

When $\pi > s$:

Under this optimal setting case 2, case 4 and case 6 are considered. Case 2: $(p_b, p_b^T) \leq s < \pi$ clearly explains $s < \pi$ and Case 4:$s, p_b \leq p_b^T < \pi$ provides $s < \pi$. The profit comparison between Case 4 and Case 2 is given by,

$$\pi_{4a}^T - \pi_{2a}^T = (d_1^I - d_2^I)(s - p_b^T) \tag{38}$$

Eq. (38) shows that buyback is not possible. Case 2 dominates Case 4. Optimal profit of Case 6 and Case 2 is now compared.

For increasing demand, $d_1^d \leq d_2^d \; and \; d_1^I \leq d_2^I$

$$\pi_{6a}^T - \pi_{2a}^T = \{\gamma\theta p_x(1-\zeta) - p_b^T - c_r^T + s\zeta\}d_1^I \tag{39}$$

For decreasing demand, $d_1^d > d_2^d \; and \; d_1^I > d_2^I$

$$\pi_{6b}^T - \pi_{2b}^T = \{\gamma\theta p_x(1-\zeta) - c_r^T + s\zeta\}d_2^I - (p_b^T + s)d_1^d + sd_2^d \tag{40}$$

Buyback is possible if $\pi < p_b^T < (\gamma\theta p_x - c_r^T)$, TPR should pay buyback price slightly more than the additional profit of the independent repair shop. TPR gives $p_b^T = \pi + \varepsilon$ to independent repair shop to collect all the damaged/broken parts.

4.6 Optimal profit of OEM varies depending on the relationship of salvage revenue and additional unit profit of independent repair shop

Relationship of salvage revenue and additional unit profit affects the buyback decision of OEM as well as TPR.

When $\pi < s$

Under this setting only case 1 is considerable, where salvage revenue exceeds all other revenues. When independent repair shop earns profit based on this strategy, profit difference between case5 and case1 helps to determine buyback price of OEM.

$$\pi_{4a}^o - \pi_1^o = \left(c_p^o - c_r^o - p_b\right)d_1^I \text{ ; For increasing demand } d_1^I \leq d_2^I \tag{41}$$

$$\pi_{4b}^o - \pi_1^o = \left(c_p^o - c_r^o - s\right)\zeta d_2^I - d_1^I(p_b - s) \text{ ; For decreasing demand } d_1^I > d_2^I \tag{42}$$

Buyback price p_b of the OEM should be larger than salvage revenue and should be enough smaller than profit from remanufacturing $(c_p^o - c_r^o)$.OEM pays $p_b = s + \lambda$ where, $s < p_b < c_p^o - c_r^o$ to independent repair shop to encourage to sell all the damaged/broken parts.

When $\pi > s$

Under the above setting, Case 2 and Case 3 are considered as in both cases unit profit from repaired parts is larger than salvage revenue. In Case 3, buyback price is larger than salvage revenue but additional unit profit π exceeds buyback price. First of all, OEM compares Case 3 and Case 2 to find out the optimal buyback price.

$$\pi_3^o - \pi_2^o = -(p_b - s)(d_1^I - d_2^I) \tag{43}$$

The comparison gives negative value which shows that Case 2 dominates Case 3. It is not reasonable to select buyback price between the interval (s, π) thus buyback is not possible for Case 3. OEM compares the optimal profit of Case 5 and Case 2 to identify an appropriate buyback price.

$$\pi_{5a}^{o} - \pi_{2}^{o} = d_1^I\{\gamma p_x\zeta + c_p^o(1-\zeta) - c_r^o - p_b\} \text{ For increasing demand } d_1^I \le d_2^I \tag{44}$$

$$\pi_{5b}^{o} - \pi_{2}^{o} = (\gamma p_x - c_r^o - s)\zeta d_2^I - d_1^I(p_b - s) \text{ For decreasing demand } d_1^I > d_2^I \tag{45}$$

OEM earns profit $(\gamma p_x - c_r^o)$ by selling remanufactured parts. Buyback price p_b of the OEM should be larger than unit profit of independent repair shop and should be larger than buyback price of TPR.OEM pays buyback price $p_b = \pi + \lambda$ where $\lambda > \varepsilon$ and $\pi < \pi + \varepsilon < p_b < (\gamma p_x - c_r^o)$ to independent repair shop to sell all damaged/broken parts. Table 3 helps TPR and OEM to select their optimal buyback price (s).

5. Numerical analysis

In this article authors assumed some values of the parameters to show the applicability of this model.

For, increasing demand i.e. d_1^I = 100 units and d_2^I=200 units:

Case 1: when $\alpha = 0.9, \beta = 0.9, \gamma = 0.81$ and $\theta = 0.729$, unit price for remanufactured parts paid by the customers from TPR, αp_x becomes \$450 where unit price for new parts paid by the customers from OEM is assumed \$500. Unit price paid by the customers for repaired parts from local repair shop $\alpha\beta p_x$ is \$405. Unit price paid by the TPR and repair shop for new/remanufactured parts from OEM γp_x is \$405 and unit price paid by the repair shop for remanufactured parts from the TPR $\gamma\theta p_x$ is \$295.24. For these particular values repair shop makes additional profit by selling repaired parts, $\pi = \$204.02$ for demand of new parts from OEM at repair shop is ζ=0.9 and demand of remanufactured parts from TPR is (1-ζ)=0.1. From the equation $c_r^o < \gamma p_x\zeta + c_p^o(1-\zeta) - \pi$, remanufacturing cost of the OEM is calculated for $c_r^o < \$200.475$. From $c_r^T < \gamma\theta p_x - \pi$ authors obtained remanufacturing cost of TPR i.e. $c_r^T < \$91.22$. For unit remanufacturing cost of \$11.22 TPR would not buyback damaged parts from repair shop as $\pi_{6a}^T - \pi_{2a}^T < \pi$. So OEM needs to add slightly with the additional unit profit π of the repair shop to buyback the damaged parts. As$\{\gamma p_x\zeta + c_p^o(1-\zeta) - c_r^o - p_b\} > \pi$, then buyback price should be $p_b < \gamma p_x\zeta + c_p^o(1-\zeta) - c_r^o - \pi$. From this expression OEM pays an incentive (\$0<λ<\$190) with additional unit profit of repair shop π to select buyback price. i.e. $p_b = \$209.02$ where value of λ=\$5/unit. Profit of OEM is $\pi_{5a}^o - \pi_2^o = \$18{,}450$.

Case2: When demand of new parts from OEM at repair shop is ζ=0.3 and demand of remanufactured parts from TPR is (1-ζ)=0.7 and the values of cost parameters are same as described in case 1, the additional unit profit of repair shop π is \$168.17. TPR collects the damaged parts from the repair shop at maximum unit buyback price of $p_b^T = \$198.17$. TPR obtains its profit, $\pi_{6a}^T - \pi_{2a}^T = \$233$ for remanufacturing cost \$7.07. An incentive $\varepsilon = \$30$/unit is added to additional unit profit of repair shop to select buyback price. OEM pays more incentive ($\lambda > \varepsilon$) than TPR for collecting damaged parts from repair shop i.e. p_b=\$208.17 where $30 < \lambda \le 40$. Optimal profit of OEM is $\pi_{5a}^o - \pi_2^o = \$18{,}650$.

Case3: When $\alpha = 0.3, \beta = 0.9, \gamma = 0.81$ and $\theta = 0.729$, the additional profit earned by repair shop is π= -\$35.97/unit. Repair shop decides to sell all the damaged parts to the recyclers as salvage revenue (\$3 per unit) is more profitable than unit profit from repairing. In such case, if optimal profit of TPR is $\pi_{6a}^T - \pi_{2a}^T < 0$, TPR would not buyback parts. For this, OEM pays incentive which is slightly more than salvage revenue to collect damaged parts. OEM selects its minimum buyback price $p_b = \$8$ per unit and earns maximum profit $\pi_{5a}^o - \pi_2^o = \$38553$. For decreasing demand, $d_1^I > d_2^I$ if profit difference of TPR is $\pi_{6b}^T - \pi_{2b}^T > 0$, TPR goes for collecting damaged parts from independent repair shop. In such case, if optimal profit of the OEM is $\pi_{5a}^o - \pi_2^o > 0$, OEM will compete with TPR for selecting buy back price of damaged/broken parts from independent repair shop. Otherwise, they both will not got for collecting damaged parts from repair shop.

Table 3
Selection of buyback price of TPR and OEM

	Profit from remanufacturing	$\pi < s$	$\pi > s$
TPR		Compare profit for rising and falling demand. If, $\pi_{6a}^T - \pi_{1a}^T \leq 0$ and $\pi_{6b}^T - \pi_{1b}^T \leq 0$, then buyback is not possible. If, $\pi_{6a}^T - \pi_{1a}^T > 0$ and $\pi_{6b}^T - \pi_{1b}^T > 0$, then buyback is possible and $p_b^T = s + \epsilon$;	If$\pi \geq \gamma\theta p_x - c_r^T$, buyback is not possible. If$\pi < \gamma\theta p_x - c_r^T$, buyback is possible. For rising demand $p_b^T = \pi + \epsilon$; For falling demand, compare profit, if $\pi_{6b}^T - \pi_{2b}^T \leq 0$ then buyback is not possible $\pi_{6b}^T - \pi_{2b}^T > 0$ then buyback is possible and $p_b^T = \pi + \varepsilon$
OEM	$(c_p^o - c_r^o - s) \leq 0$	No buyback	For rising demand if $\pi_{5a}^o - \pi_2^o > 0$;$p_b = \pi + \lambda$, $where, \lambda > \varepsilon$ For falling demand if $\pi_{5b}^o - \pi_2^o > 0$; $p_b = \pi + \lambda,\ ,\lambda > \varepsilon$ If $\pi_{5a}^o - \pi_2^o \leq 0 =$ $no\ buyback$ $\pi_{5b}^o - \pi_2^o \leq 0 = no\ buyback$
	$(c_p^o - c_r^o - s) > 0$	For rising demand if TPR selects its buyback price$p_b^T = s + \varepsilon$; then OEM selects its buyback price$p_b = s + \lambda$; where, λ>ε. If TPR does not buyback damaged parts under this setting then OEM needs to select buyback price only larger than salvage revenue of independent repair shop, i.e. $p_b = s + \lambda$, where λ>s. For falling demand compare the profit, $\pi_{4b}^o - \pi_1^o > 0$ Then buyback is possible. If TPR pays$p_b^T = s + \varepsilon$; then OEM will select$p_b = s + \lambda$; where, λ>ε; otherwise OEM will select$p_b = s + \lambda$, where λ>s. If $\pi_{4b}^o - \pi_1^o \leq 0$= no buyback	If $\pi \geq (\gamma p_x - c_r^o)$ buyback is not possible If $\pi < (\gamma p_x - c_r^o)$ then for rising demand $p_b = \pi + \lambda,\ where, \lambda > \varepsilon$ For falling demand, compare profit, $if\ \pi_{5b}^o - \pi_2^o > 0; then,\ p_b = \pi + \lambda, where, \lambda > \varepsilon$ $if\ \pi_{5b}^o - \pi_2^o \leq 0$, Then buyback is not possible.

6. Findings

OEM has control over selection of the original market price of the new parts. Depending on the original market price of the new parts (p_x), TPR and independent repair shop may select their selling price of remanufactured and repaired parts respectively. Buyback price of the OEM and TPR depends on the additional unit profit of the independent repair shop (π). If independent repair shop earns more profit by selling repaired parts then TPR and OEM has to pay more incentive added with additional unit profit for deciding buyback price for collecting damaged/broken parts. Here authors assumed price sensitivity factors, to help OEM to identify an appropriate selling price of new parts(p_x), according to which other cost parameters (selling price of repaired parts and selling price of remanufactured parts of TPR) change. For the deterministic demand according to the change of the cost parameters OEM can identify additional unit profit of the independent repair shop and also can identify the particular value of cost parameters for which TPR will not go for buying back damaged parts from independent repair shop. Thus OEM can select the optimal buyback price to collect all the damaged parts from the independent repair shop. OEM can identify the specific profit region where repair shop makes minimum profit and for which OEM has to pay minimum buyback price.

7. Conclusion

This two-period buyback pricing model shows competition between TPR and OEM for selecting optimal buyback price(s). Optimal buyback price (s) of each individual player depend on π_r (additional unit profit of repair shop earned by selling repaired parts) and s (salvage revenue earned by recycling damaged/broken parts). TPR and OEM obtain their optimal profit expression(s) under different optimal strategies of repair shop. Relationship between π_r (additional unit profit of repair shop earned by selling repaired parts) and s (salvage revenue earned by recycling damaged/broken parts) have great impact on optimal profit responses of each individual player for increasing and decreasing demand. Numerical example shows that each player can determine the upper limit of their remanufacturing cost. When repair shop selects repairing operation instead of recycling, then TPR and OEM select remanufacturing cost in such way that remanufacturing profit exceeds the additional profit of repair shop. Thus lower limit and upper limit of buyback price(s) for each individual player is determined. This model helps to identify appropriate remanufacturing cost, buyback price and optimal profit of TPR and OEM. For the future extension it will be more interesting while exchange/discount offer will replace buyback price and demand become stochastic. TPR and OEM can give different exciting offer to independent repair shop to stop repair shop to perform product recovery activity. Independent repair shop selects any one offer either from OEM or from TPR to return the damaged parts. We considered single type of part in this model. It can be extended for multiple type of part.

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