Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 8, No. 1, 2023

New Energy Vehicle Pricing Strategy Based on Residual Value Estimation

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Abstract: With the increasing depletion of traditional resources such as oil and the promotion of new energy vehicles by national policies, the production and purchase of new energy vehicles are increasing day by day, but the proportion of new energy vehicles in total vehicle sales is still low compared to the sales of traditional vehicles. Therefore, this paper investigates the influence of consumers' residual value estimation on consumers' purchasing behavior when purchasing new energy vehicles by analyzing consumers' purchasing decisions and producers' production decisions, and finds that: consumers' residual value estimation affects producers' decisions, and for the case where producers sell only one product, the best strategy choice is achieved by comparing different solutions; in ensuring that new energy used vehicles have value, the residual value has a greater impact on consumer purchase, and the sales price will increase with the increase of residual value estimation; new energy vehicle enterprises can increase consumers' willingness to purchase new energy vehicles, enhance the profits of vehicle enterprises, and promote the promotion of new energy vehicles by improving the residual value rate of new energy vehicles.

Keywords: New energy vehicles, Recycling pricing, Closed-loop supply chain, Residual value estimation.

1. Introduction

With the over-exploitation of fossil energy and the increasing depletion of traditional energy sources such as oil, the development of new energy vehicle industry is an inevitable requirement for the development of a low-carbon green economy, and the government has successively introduced various tax incentives including financial subsidies, purchase tax, and consumption tax to support the research and development of new energy vehicles in China. The relevant policies have indeed stimulated the consumption of electric vehicles to a certain extent, however, with the decrease of government subsidies year by year, the sales of new energy vehicles have also declined significantly. In addition, during the acquisition process, consumers have started to include the level of residual value into the overall purchase cost. For example, the initial selling price of an EV of a certain brand is higher than that of a fuel car of the same model, and the cost of using it in 3 years is lower than that of a fuel car due to the relatively low power and maintenance costs. However, if we consider the residual value level after 3 years, the total cost of the EV is still higher than that of the fuel car. Therefore, the low residual value of new energy vehicles is one of the reasons for their declining sales. Moreover, the low residual value of new energy vehicles also affects their transaction cost and circulation value in the used car market. Therefore, how the pricing decision between consumers and production changes when considering the residual value of new energy vehicles, and how to deal with the diseconomics of new energy vehicles caused by low residual value of new energy vehicles becomes an urgent issue to be solved.

2. Literature Review

The research content of this paper mainly involves the two aspects of centralized drug procurement and drug supply chain coordination, and the relevant literature will be sorted out from these two aspects.

2.1. Centralized drug procurement

Currently, most of the modeling research on centralized procurement of drugs is carried out from the perspective of maximizing supply chain profits. For example, Hu et al. (2012) construct a supply chain model of a drug manufacturer, a GPO, and n suppliers (hospitals, etc.). They use game theory to analyze the impact of factors such as contract management fees and membership fees on supply chain performance. They find that the higher the efficiency of the GPO contract, the higher the profit each supply chain member can receive. Safaei and Heidarpoor et al. (2017) assume that pharmacies have procurement partnerships with neighboring pharmacies. They construct a multi-objective optimization model with multiple pharmacies, multiple suppliers, and GPO clusters. They conclude that GPOs could reduce pharmacies' procurement costs and increase supply chain profits.

2.2. Pharmaceutical supply chain coordination

Another issue relevant to this study is the study of coordination contracts in the pharmaceutical supply chain. In the existing literature, most of the research issues of drug supply chain coordination by scholars do not involve group purchasing organizations. For example, Ma et al. (2019) study the impact of patient attention levels of drug manufacturers and retailers on corporate pricing and quality decisions. They propose the selection conditions for wholesale price contracts and revenue-sharing contracts that achieve corporate profit Pareto. Tat et al. (2020) consider that the drug supply chain including drug suppliers and retailers can resell excess drugs in the secondary market, constructing a centralized and decentralized model. In follow-up work, they propose a combination model of drug repurchase plus shortage risk sharing to achieve supply chain coordination, which concludes that this model can coordinate the drug supply chain and improve the overall profit.

Given this, this paper considers the characteristics of the actual drug supply chain involving centralized procurement and the public welfare of medical institutions, constructs a drug supply chain model with different decision-making modes, and proposes an appropriate coordination contract from the perspective of GPO platform and medical institution cooperation to achieve a win-win situation for members of the pharmaceutical supply chain and the improvement of the overall social welfare. In addition, combined with China's current drug policy, the feasibility of the coordination contract is demonstrated, and the effectiveness of the designed contract model on the contract coordination of the drug supply chain under the influence of centralized procurement and public welfare is verified through case analysis.

3. Problem Description

Suppose there are two groups of car manufacturers and consumers in the closed-loop supply chain, with energy shortage becoming more and more serious, and the low value retention rate restricting consumers' purchase. For simplicity, this paper only considers the impact of the selling price and the recycling price on the consumer's purchase decision, and the willingness to pay is not affected by other factors.

The sequence of events: first, the producer decides the price of the product, then the consumer decides whether to buy the product; after the product life cycle, the producer decides z the final recycling price, then the consumer decides whether to sell the used car. There are three natural time sequences, so it is a three-stage dynamic game.

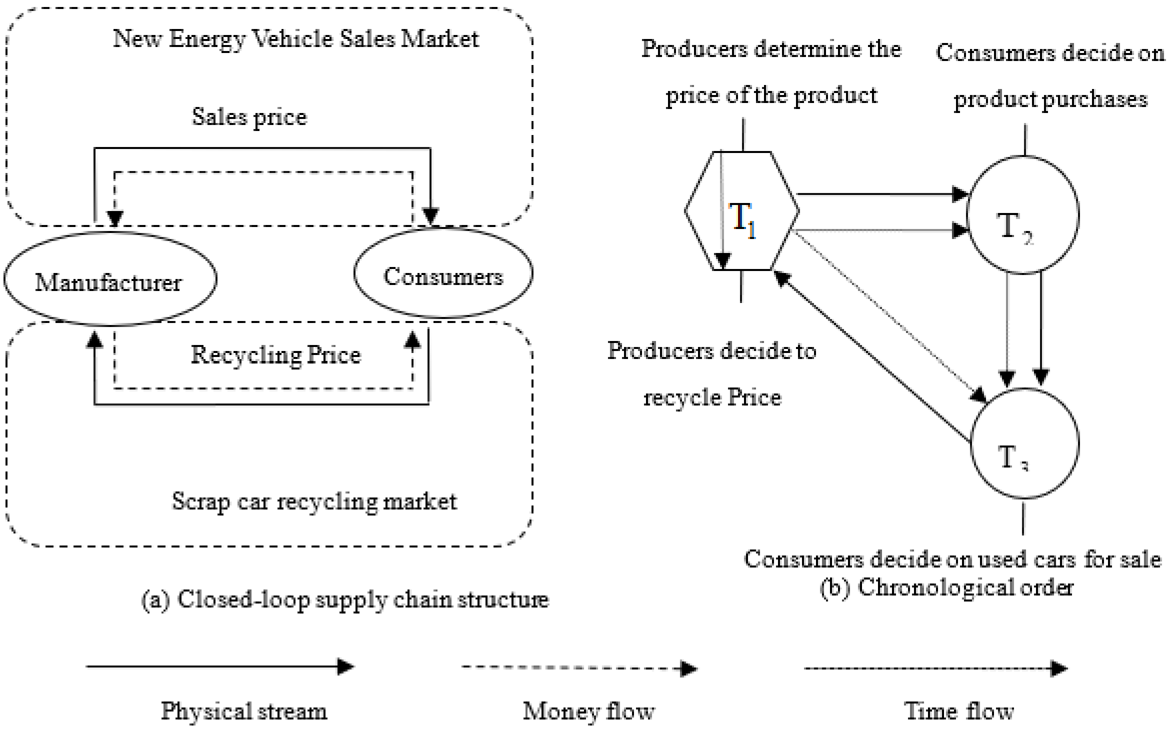


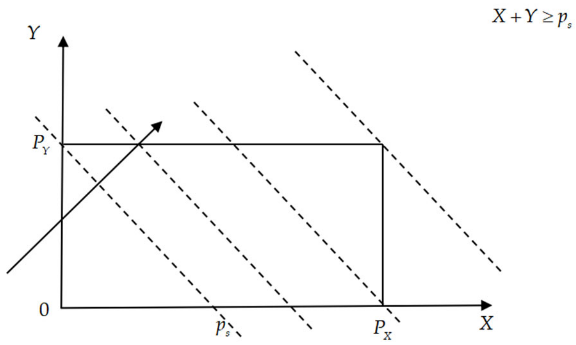
Figure 1. Considering the closed-loop supply chain structure and the order of decision-making

Table 1. Variable symbols and definitions

Variable Symbols	Variable Meaning	Variable Symbols	Variable Meaning
p_r	Recycling Price	X	Willingness to pay
p_s	Sales price	P_X	Maximum willingness to pay
g_r	Processing profit	Π_{Ms}	Sales Profit
μ	Production costs	Π_{Mr}	Recovery profit
Y	Residual value estimation	Π_M	Total profit
P_Y	Consumer estimates of the maximum residual value of used cars		

4. Model

4.1. Model considering residual value estimation



Consumers: Consumers in the purchase phase have a willingness to pay for the product and an estimate of the salvage value of the product in case of later recall. Define X as the consumer's willingness to pay and, for simplicity, assume that X obeys a uniform distribution of $[0, P_X]$, where P_X denotes the maximum willingness to pay among consumers. However, the estimate of the salvage value of the car affects consumer demand. Assume that the potential consumer market size is normalized to 1. Therefore, with other assumptions held constant, consumers will buy the product when $X + Y \geq p_s$ (as shown) and vice versa, and the selling price $p_s > p_r$. Therefore, consumer demand is:

$$q_s = \begin{cases} 1 - \dfrac{p_s^2}{2P_X P_Y} & 0 < p_s \leq P_Y \\ \dfrac{-2p_s + P_Y + 2P_X}{2P_X} & P_Y < p_s \leq P_X \\ \dfrac{(P_X - p_s + P_Y)^2}{2P_X P_Y} & P_Y < p_s \leq P_X + P_Y \end{cases} \tag{1}$$

At the end of the product life cycle, consumers who have previously purchased the product become the suppliers of the recycling market, and consumers have certain estimates of the current product value. The consumer's salvage value estimate Y becomes a random sample of the salvage value estimate as a whole, and therefore still obeys a uniform distribution with $[0, P_Y]$, usually, $P_X > P_Y$.

The density of its distribution becomes:

$$f_{Y'}(y') = \begin{cases} \dfrac{q_s}{P_Y} & \text{if } 0 \leq y' \leq P_Y \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

When a consumer sells a used product, he or she considers the relationship between the recycling price p_r informed by the producer and the salvage value estimate Y. Only when $p_r > Y$, the consumers will choose to sell the product, otherwise they will not. With this the number of products that consumers are willing to sell is:

$$q_r = \frac{q_s}{P_Y} p_r \tag{3}$$

Where $p_r \leq P_Y$, because at that time $p_r > P_Y$, $q_r > q_s$, the number of recovered cars exceeds the number of sales, which is not consistent with the actual situation.

Producer: the production cost per unit of product is μ, the selling price of the new energy vehicle is p_s ($\mu < p_s$ to ensure that the producer can manufacture the product for profit), and the sales profit $\prod_{MS}$ is:

$$\prod_{MS} = (p_s - \mu) q_s \tag{4}$$

At the end of the product's life cycle, the producer will recycle the product that has been sold for environmental protection and other factors, assuming that its processing profit is g_r, (g_r is the profit remaining after processing after the producer recycles the used product, excluding the recycling price, and $\mu > g_r$), then the producer's profit $\prod_{MR}$ at the recycling stage is:

$$\prod_{MR} = (g_r - p_r) q_r \tag{5}$$

The producer's profit in the whole closed-loop supply chain is:

$$\prod_M = (g_r - p_r) q_r + (p_s - \mu) q_s \tag{6}$$

The producer's decision model is: after considering the mutual influence between decisions, the producer's product price and recycling price decisions in the sales stage are not made simultaneously, but the optimal price p_s^* of the product is first decided by maximizing the overall profit, i.e., equation (6), and then the optimal recycling price p_r^* is decided by maximizing the recycling profit, i.e., the producer's announcement of the recycling price itself is actually a two-stage dynamic game.

The inverse induction method is used to solve the problem. There are two decisions in the second stage, the product purchase decision of the consumer and the used car sale decision, whose optimal decisions have been given by equations (6) and (3), respectively. To solve the optimal decision of the producer in the first stage, first substitute equation (3) into the recycling profit function equation (4) to solve for the optimal recycling price $p_r^*(p_s)$, then substitute equation (5) and equation (4) into the total profit function equation of the producer, and then substitute $p_r^*(p_s)$ into the total profit function and derive the total profit function to solve for the optimal product price p_s^* of the producer (see Appendix 1 for the specific calculation steps).

Proposition 1.The producer's optimal product price p_s^* and recycling price p_r^* are given by Table 2.

Table 2. Producer's optimal product price and recovery price

	$0 < g_r \le 2P_Y$		$g_r \ge 2P_Y$	
	$0 < \mu < P_X - \frac{1}{2}P_Y$	$\mu > P_X - \frac{1}{2}P_Y$	$0<\mu<P_X - \frac{3}{2}P_Y$	$\mu > P_X - \frac{3}{2}P_Y$
p_s^*	$\frac{-g_r^2 + 4\mu P_Y + 2P_Y^2 + 4P_Y P_X}{8P_Y}$	P_Y	$\frac{1}{4}(2\mu - 2g_r + 3P_Y + 2P_X)$	P_Y
p_r^*	$\frac{g_r}{2}$	$\frac{g_r}{2}$	P_Y	P_Y

The proof of Proposition 1 and the other proofs of theorems and propositions are given in the appendix.

Proposition 1 shows that when the consumer decision considers the residual value estimate, when the selling price $P_Y < p_s \le P_X$ and the production cost is low, the optimal product price p_s^* is an increasing function of the unit product production cost μ, the consumer willingness to pay P_X and the consumer residual value estimate P_Y, and a decreasing function of the unit used car disposal profit g_r. That is, the producer's product pricing will increase with the production cost, the consumer willingness to pay and the consumer residual value estimate and increases and decreases as the unit used car disposal profit increases; the optimal recycling price p_r^* is is an increasing function of the unit used car disposal profit g_r and the consumer salvage estimate P_Y, i.e., the producer's recycling price will increase as the unit used car disposal profit and the consumer salvage estimate increase.

When the production cost is high, the unit used car disposal profit will no longer affect the optimal selling price, and the optimal recovery price p_r^* is an increasing function of the unit used car disposal profit g_r, and the consumer residual value estimate P_Y. That is, the producer's recovery price will increase as the unit used car disposal profit and the consumer residual value estimate increase.

The equilibrium sales quantity q_s^* can be obtained by substituting the producer's optimal product price p_s^* in Proposition 1 into the (1) equation, then substituting q_s^* and the producer's optimal price p_r^* in Proposition 1 into the (3) equation to obtain the equilibrium recovery quantity q_r^*, and substituting p_s^* 、 q_s^* 、 p_r^* and q_r^* into the (6) equation to obtain the producer's equilibrium total profit Π_M^*. The results are shown in Table 3.

Table 3. Equilibrium results when consumers consider residual value estimation

	$0 < g_r \le 2P_Y$		$g_r \ge 2P_Y$	
	$0 < \mu < P_X - \frac{1}{2}P_Y$	$\mu > P_X - \frac{1}{2}P_Y$	$0<\mu<P_X - \frac{3}{2}P_Y$	$\mu > P_X - \frac{3}{2}P_Y$
q_s^*	$\frac{g_r^2 + 2P_Y(-2\mu + P_Y + 2P_X)}{8P_Y P_X}$	$1 - \frac{P_Y}{2P_X}$	$-\frac{2\mu - 2g_r + P_Y - 2P_X}{4P_X}$	$1 - \frac{P_Y}{2P_X}$
q_r^*	$\frac{g_r^3 + 2g_r P_Y(-2\mu + P_Y + 2P_X)}{16P_Y^2 P_X}$	$\frac{1}{4}g_r\left(-\frac{1}{P_X} + \frac{2}{P_Y}\right)$	$-\frac{2\mu - 2g_r + P_Y - 2P_X}{4P_X}$	$1 - \frac{P_Y}{2P_X}$
Π_M^*	$\frac{\left(g_r^2 + 2P_Y(-2\mu + P_Y + 2P_X)\right)^2}{64P_Y^2 P_X}$	$\frac{\left(g_r^2 + 4P_V(-\mu + P_V)\right)(P_V - 2P_X)}{8P_V P_X}$	$\frac{(2\mu - 2g_r + P_Y - 2P_X)^2}{16P_X}$	$\frac{(\mu - g_r)(P_Y - 2P_X)}{2P_X}$

Table 3 shows that if the disposal profit is not high (i.e., $0 < g_r < 2P_Y$), only part of the used and discarded products will be recycled under the premise that consumers consider used cars to have salvage value, and if the disposal profit is high enough (i.e., $g_r \ge 2P_Y$), all sold products will be recycled and the circular economy will be fully realized.

4.2. Model without considering residual value estimation

Consumer C **:** has a willingness to pay for the product and has a salvage value estimate for the used car. Define X as willingness to pay and Y as salvage value estimate, both of which are independent of each other. For simplicity, assume that X obeys a uniform distribution with $[0, P_X]$, where P_X denotes the maximum willingness to pay among consumers, and Y obeys a uniform distribution with $[0, P_Y]$, where PR denotes the maximum salvage estimate among consumers. Usually, $P_X > P_Y$.

Consumers will consider the relationship between willingness to pay X and product price p_s when they buy the product, when $X \geq p_s$, consumers will buy the product, and vice versa, so the consumer demand is:

$$q_s = 1 - \frac{p_s}{P_X} \tag{7}$$

$p_s \leq P_X$ in equation (7) because $p_s > P_X$ when $q_s < 0$, when there is no product demand.

After the end of the product life cycle, the consumer sale volume remains in equation (3).

Producer M : Product sales profit Π_{MS} and recovery profit Π_{MR} remain as well as total profit remains (4) (5) (6) respectively.

The solution is solved by the inverse induction method. There are two decisions in the second stage, namely, the consumer's product purchase decision and the used car sale decision, whose optimal decisions have been given by Eqs. (7) and (3), respectively. To solve the optimal decision of the producer in the first stage, first substitute equation (3) into the recycling profit function equation (5) to solve for the optimal recycling price $p_r^*(p_s)$, then substitute equation (7) and equation (3) into the total producer profit function equation (6), then substitute $p_r^*(p_s)$ into the result to solve for the optimal producer product price p_s^*, and finally reverse substitution.

Proposition 2.The producer's optimal product price p_s^* and recycling price p_r^* are given by Table 4.

Table 4. Producer's optimal product price and recovery price

	$0 < g_r \leq 2P_Y$	$g_r \geq 2P_Y$
p_s^*	$\frac{4P_Y(P_X+\mu)-g_r^2}{8P_Y}$	$\frac{(P_X+\mu)-(g_r-P_Y)}{2}$
p_r^*	$\frac{g_r}{2}$	P_Y

Proposition 2 shows that the optimal product price p_s^* is an increasing function of unit product production cost μ, consumer willingness to pay P_X and consumer residual value estimate P_Y, and a decreasing function of unit used car disposal profit g_r .That is, the producer's product pricing will increase with the increase in production cost, consumer willingness to pay, and consumer residual value estimate, and decrease with the increase in unit used car disposal profit The optimal recycling price p_r^* is an increasing function of the unit used car disposal profit g_r and the consumer salvage estimate P_Y, i.e., the producer's recycling price will increase with the increase of the unit used car disposal profit and the consumer salvage estimate.

Substituting the producer's optimal product price p_s^* in Proposition 2 into equation (7) yields the equilibrium quantity sold q_s^*. Substituting q_s^* and the producer's optimal price p_r^* in Proposition 2 into equation (3) yields the equilibrium quantity recovered q_r^*. Substituting p_s^* 、 q_s^* 、 p_r^* and q_r^* into equation (6) yields the producer's equilibrium total profit Π_M^*. The results are shown in Table 5.

Table 5. Equilibrium results for consumers without considering residual value estimates

	$0 < g_r \leq 2P_Y$	$g_r \geq 2P_Y$
q_s^*	$\frac{4P_Y(P_X-\mu)+g_r^2}{8P_XP_Y}$	$\frac{(P_X-\mu)+(g_r-P_Y)}{2P_X}$
q_r^*	$\frac{g_r(4P_Y(P_X-\mu)+g_r^2)}{16P_XP_Y^2}$	$\frac{(P_X-\mu)+(g_r-P_Y)}{2P_X}$
Π_M^*	$\frac{(4P_Y(P_X-\mu)+g_r^2)^2}{64P_XP_Y^2}$	$\frac{((P_X-\mu)+(g_r-P_Y))^2}{4P_X}$

Table 5 shows that under the premise that consumers consider used cars to have salvage value, if the disposal profit is not high (i.e., $0 < g_r < 2P_Y$), only part of the used and discarded products will be recycled, and if the disposal profit is high enough (i.e., $g_r \geq 2P_Y$), all sold products will be recycled and the circular economy will be fully realized.

5. Balanced Strategy and Analysis of Results

This section compares the equilibrium differences between the consumer's decision to consider salvage estimates at the time of purchase and the decision not to consider salvage estimates. To facilitate the distinction and expression, subscripts Ⅰand Ⅱ are added, such as $p^*_{s-\mathrm{I}}$ to denote the equilibrium price of the product when residual value estimation is considered, $p^*_{s-\mathrm{II}}$ to denote the equilibrium price without considering residual value estimation, and so on.

Proposition 3. $p^*_{s-\mathrm{I}} > p^*_{s-\mathrm{II}}$ 、 $q^*_{s-\mathrm{I}} > q^*_{s-\mathrm{II}}$ ， $p^*_{r-\mathrm{I}} = p^*_{r-\mathrm{II}}$ 、 $q^*_{r-\mathrm{I}} > q^*_{r-\mathrm{II}}$.

Proposition 4. $\Pi^*_{M-\mathrm{I}} > \Pi^*_{M-\mathrm{II}}$.

Propositions 3 and 4 show that when it is profitable for the producer to recycle used cars, the equilibrium product price is higher under the salvage estimate than under the salvage estimate, except that the equilibrium recycling price remains the same under both decision alternatives, and both the equilibrium product sales and recycling quantity are higher than under the salvage estimate. When the profit per unit of used car disposal is greater than zero, the equilibrium total profit that the producer can obtain without considering the salvage estimate is higher than the equilibrium total profit that can be obtained without considering the salvage estimate. It can be seen that, for the better development of enterprises, new energy vehicle enterprises can try to guide consumers to recognize the importance of salvage value. Due to the limitation of battery life and the cost of getting a new car, the old car retention rate of new cars will basically not exceed 50% after three years. Although the retention of some hybrid cars is quite good, but in some urban areas, only accept the pure electric car customers, the residual value is still a great constraint on their willingness to buy a car. Therefore car companies can use buy-back programs or provide multi-year warranty services to enhance the residual value of cars and thus promote business development.

6. Conclusion

This paper constructs a two-stage dynamic game model based on the minimal closed-loop supply chain structure with full consideration of consumers' decision-making behavior to analyze which decision the producer should take in the production decision and recycling decision in the closed-loop supply chain: whether the consumer considers salvage estimation or not. It is found that when the profit per unit of used car disposal is greater than zero, consumers consider residual value estimation can make producers increase product prices, sell more products, and recycle more used cars, thus gaining higher total profits, when consumers consider [16]

residual value estimation is the optimal decision for producers in the closed-loop supply chain. Therefore, it is profitable for producers to increase the residual value of used cars and thus promote the residual value estimation of consumers, and by increasing the residual value estimation, the demand for new energy vehicles can be increased, thus achieving the purpose of promoting new energy vehicles.

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