Received: 4 May 2023 | Revised: 27 June 2023 | Accepted: 25 July 2023 | Published online: 2 August 2023

Green and Low-Carbon Economy
2024, Vol. 2(4) 219–230
DOI: 10.47852/bonviewGLCE32021036
BON VIEW PUBLISHING

RESEARCH ARTICLE

# Research on the Trade-In Pricing Strategy of New Energy Vehicle Producers Considering the Consumers' Heterogeneous Behavior

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**Abstract:** In practice, trade-ins are offered by new energy vehicle (NEV) producers and include trade-in-for-new fuel vehicles and trade-in-for-NEVs. By using the game-analytical method, we mainly analyze the optimal pricing strategy of NEV producers when they provide both of the above-mentioned trade-in services. The results show that automobile producers should consider the production cost of new vehicles and the trade-in rebate when they provide a trade-in strategy. On the one hand, when the production cost of new vehicles is high but the trade-in rebate is very low, automobile producers do not provide the trade-in service. On the other hand, when the production cost of new vehicles is very low but the trade-in rebate is very high, automobile producers should provide trade-in services to heterogeneous consumers. Moreover, when the heterogeneous behavior of consumers is strong and the innovation value of new-generation fuel vehicles is low, automobile producers should choose the preannounce pricing strategy. Otherwise, these producers should adopt the dynamic pricing strategy.

**Keywords:** trade-ins, heterogeneous consumers, preannounce pricing strategy, dynamic pricing strategy, trade-in-for-new fuel vehicles, trade-in-for-new energy vehicles

## 1. Introduction

### 1.1. Background and motivation

With the rapid progress of society and the rapid development of the economy, the environmental problems faced by the government are increasing yearly. Although a series of measures have been taken to ease environmental pressure, it is still difficult to meet the strict requirements of the public for the environment. The fossil energy consumption structure is one of the main causes of environmental pollution. Regarding the relationship between energy consumption and environmental impact, a large number of studies show that the structure of energy consumption has both long-term and short-term effects on different pollutants.

To promote energy saving and emission reduction, decrease environmental pollution, and expand consumer demand, in 2009, the Ministry of Finance and the State Economic and Trade Commission in China issued the Interim Measures on the Management of Subsidy funds for scrapping and Renewal of old automobiles. These measures clearly stipulate the vehicle subsidy scope and subsidy standard of the old car scrapping subsidy fund. They mark the beginning of the implementation of the subsidy policy of trading-in programs. Since then, many automobile producers and consumers have participated in trade-in programs and gained many benefits. With the continuous decline in government subsidies, many new fuel vehicle producers have launched their own trade-in service. For example, the service of trading-in-for-new fuel vehicles offered by automobile producers such as Guangqi Toyota and Dongfeng Nissan means that automobile consumers can purchase new fuel vehicles at a certain discount price by participating in trade-in service. For example, in 2022, the annual sales volume of Guangqi Toyota exceeded 1 million, among which the sales volume by trading-in for new ones exceeded 200,000. Therefore, trade-in service is not only a measure to protect the environment but also an enterprise behavior to stimulate consumers to repeatedly purchase and upgrade products.

In recent years, with the government's attention to new energy vehicles (NEVs) and the continuous enhancement of consumer awareness of environmental protection, NEVs have been rapidly developing. In the *Automobile Industry Adjustment and Revitalization Plan* issued by the Chinese government in 2009, it was mentioned that "the national energy-saving and NEV demonstration project should be launched, and the government will arrange funds to provide subsidies." In the same year, the Ministry of Finance issued the *Notice on Carrying Out the Demonstration and Promotion Pilot Work of Energy-saving and New Energy Vehicles*, which provided subsidies for the purchase of NEVs in the public service areas of pilot cities; thus, it opened the prelude to the subsidy era of NEVs. Then, in 2016, the

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government issued the *Notice on the Financial Support Policy for the Promotion and Application of New Energy Vehicles from 2016 to 2020*, providing subsidies to consumers who buy NEVs. In 2020, the *New Energy Automobile Industry Development Plan* (2021–2035) issued by the Ministry of Industry and Information Technology stated that it would continue to promote the electrification and online connection of automobiles. Under the influence of the above policies, some fuel vehicle producers have provided trade-in-for-new fuel vehicle services and then launched trade-in-for-NEV services. In this case, customers can choose to buy NEVs by participating in trade-in-for-NEV service and obtain the discount price provided by the automobile producer.

On the one hand, the trade-in program can encourage consumers to buy new products repeatedly, and it enables consumers to obtain many more concessions. On the other hand, the implementation of the trade-in program can also promote the sales of new products, effectively stabilize the market share, open the NEV market, and improve the profits of automobile producers. However, it should also be noted that the coexistence of trade-in-for-new fuel vehicles and trade-in-for-NEVs would also have certain adverse effects on automobile producers and consumers. On the one hand, new fuel vehicles and NEVs will compete with each other, both markets will be cannibalized, and the pricing strategies of automobile producers will become more complex. On the other hand, the simultaneous existence of two trade-in policies will lead to the gradual diversification of consumer choices. Therefore, given the coexistence of trade-in-for-new fuel vehicles and trade-in-for-NEVs, what kind of pricing strategy should automobile producers adopt?

At the same time, with the rapid development of the economy, the era of consumer dominance has come. At the same time, the choice behavior of consumers is increasingly heterogeneous, which is becoming much more obvious and will have a deep impact on the competitive behavior of enterprises. The heterogeneous behavior of consumers is manifested in many different aspects, such as consumer heterogeneity of different products, consumer heterogeneity of homogeneous products, heterogeneous preference of network effects, and heterogeneous preference of limited information. Similarly, the heterogeneous behavior of consumers will also have many impacts on automobile producers. On the one hand, consumers will prefer new fuel vehicles and buy new-generation fuel vehicles by participating in trade-in-for-new fuel vehicles. On the other hand, consumers will also prefer NEVs and will choose to buy them by participating in trade-in-for-NEVs. Therefore, how will the heterogeneous behavior of consumers affect the trade-in pricing strategy of automobile producers?

Therefore, considering the heterogeneous behavior of consumers, we examine one automobile producer that sells new fuel vehicles and NEVs to heterogeneous consumers during two different periods, and the automobile producer offers trade-in-for-new fuel vehicles and trade-in-for-NEVs simultaneously. First, we assume that the automobile producer uses the single rollover strategy (the old generation fuel vehicles stop selling when new-generation fuel vehicles are launched). We discuss the automobile producer's dynamic pricing strategy. Second, we analyze the automobile producer's preannounce pricing strategy when adopting the single rollover strategy. Third, we obtain the automobile producer's optimal pricing strategy by comparing the dynamic pricing strategy and preannounce pricing strategy.

We can obtain the following conclusions. First, for heterogeneous consumers, their choice behavior is diverse. Specifically, in Period 1, some heterogeneous consumers can choose to purchase first-generation fuel vehicles, and others choose to wait. In Period 2, some primary heterogeneous consumers choose to buy second-generation fuel vehicles, some customers choose to buy NEVs, and some others choose to continue to use old-generation fuel vehicles. Some replacement heterogeneous consumers take part in trade-in-for-new fuel vehicles, and some of them choose to participate in trade-in-for-NEVs. Second, automobile producers should consider the production cost of new vehicles and trade-in rebates when providing trade-in services. On the one hand, when the production cost is high but the trade-in rebate is very low, automobile producers do not provide the trade-in service. On the other hand, when the production cost of new vehicles is relatively low, but the trade-in rebate is very high, automobile producers should provide trade-in services to heterogeneous consumers. Third, when the heterogeneous behavior of consumers is strong and the innovation value of new-generation fuel vehicles is low, automobile producers should choose the preannounce pricing strategy. Otherwise, automobile producers should adopt the dynamic pricing strategy.

## 1.2. Contribution and structure

There are two main differences between this paper and the relevant literature, as follows: (1) most literature has discussed the trade-in problem of traditional electronic and electrical products, whereas we analyze the trade-in problem of automobile producers and (2) most literature has not considered the impact of the heterogeneous behavior of consumers on the pricing strategies of automobile producers. However, we discuss the impact of the heterogeneous behavior of consumers on the automobile producer's pricing strategy.

Compared with traditional electronic and electrical product trade-in programs, automobile product trade-ins are more complex. In the trade-in process of traditional electronic and electrical products, consumers return their old products to the firm in exchange for a new one. There is only one "trade-in" option. For automobile products, consumers have two different choices when they take part in trade-in activity. One is to trade an old fuel vehicle for a new fuel vehicle. The other is to trade an old fuel vehicle for a NEV. Therefore, automobile producers should not only decide the discount price of old fuel vehicles but also decide the selling price of new fuel vehicles and the selling price of NEVs. The pricing strategy of automobile producers is more complex.

Thus, the main contribution of this paper is that we analyze automobile producers' trade-in pricing strategy under the situation of the heterogeneous behavior of consumers and compare the difference between the dynamic pricing strategy and the preannounce pricing strategy. This paper engages with the literature in regard to the willingness to purchase NEVs and with the literature about the pricing strategy related to trade-ins and consumers' heterogeneous behavior. Moreover, this paper analyzes the impact of consumers' heterogeneous behavior on automobile producers' optimal pricing strategy. In other words, this paper discusses the automobile producer's optimal pricing strategy when we consider the consumer's heterogeneous behavior and the single rollover strategy.

The remainder of this paper is organized as follows. The literature review is described in Section 2. In Section 3, we build the game-analytical model. The choice behavior of heterogeneous consumers and the dynamic pricing strategy of the automobile producer are discussed in Section 4. In Section 5, we deeply analyze the choice behavior of heterogeneous consumers and the automobile producer's preannounce pricing strategy. In Section 6, we provide some conclusions.

## 2. Literature Review

This paper discusses an automobile producer's optimal pricing strategy for both fuel vehicles and NEVs when we consider the consumer's heterogeneous behavior and the single rollover strategy, which relates to three streams of the literature, namely the willingness to purchase NEVs, the product pricing strategy with trade-ins, and the consumer's heterogeneous behavior. Then, we review this literature to introduce the contribution of this paper.

One stream of literature examines the willingness to purchase NEVs. Understanding customers' purchasing intention of NEVs is helpful for better capturing the purchasing behavior of customers and providing accurate policy suggestions. Many studies have discussed this problem in depth. For example, Sierzchula [1] noted that NEVs could reduce environmental effects and improve an organization's public image. Silvia and Krause [2] found that subsidies could effectively improve customers' willingness to purchase NEVs by reducing vehicle purchase price via subsidies. Long et al. [3] analyzed the willingness to purchase electric vehicles in Canada. Jin et al. [4] provided the effects of customers' attitudes and vehicle restriction policies on the adoption of electric vehicles. Wang et al. [5] examined the heterogeneity and spatial autocorrelation $CO_2$ emissions of the transportation sector for 51 belt and road economies from 2000 to 2014 by using the empirical analysis. Wang et al. [6] combined the Tapio decoupling model and the logarithmic mean divisia index to analyze the relationship between transportation sector development and $CO_2$ emissions. Liu et al. [7] noted that the status symbol and innovation symbol of electric vehicles have significant positive effects. Zhou et al. [8] found that performance expectancy and effort expectancy are influencing factors on taxi drivers' intention to use electric vehicles. Wang et al. [9] mainly analyzed Chinese consumers' environmental awareness and attitude toward NEV policy and its impact on their attitude toward NEV. The above studies analyze the impact of factors such as the consumer's anxiety behavior, the consumer's environmental awareness, attitude, and preferential policy and other factors on the adoption of NEVs. What is more, the above studies analyze the influence of relevant factors on the purchase intention of NEV using the empirical methods. However, the existing literature does not use the game theory to analyze the consumers' purchase willingness to NEV. Therefore, we will discuss the impact of the consumer's heterogeneous behavior on automobile producer's pricing strategy using a two-stage game-analytical method.

Another stream of literature discusses the firm's pricing strategy within trade-in programs. Most literature is involved in the preannounce pricing strategy of traditional functional products [10–16]. However, dynamic pricing strategies are much preferred in most firms, and some literature discusses this issue. For example, Li et al. [17] developed methods to segment customers and discussed the optimal pricing strategy by using a two-period model. Yin et al. [18] discussed the firm's optimal pricing strategy by using the game model. Sheu and Choi [19] analyzed a firm's optimal trade-in rebate strategy within trade-in competition. Xiao et al. [20] discussed dynamic decisions about selling price and trade-in rebates. All of the above literature discussing trade-ins does not consider the product rollover strategy [16, 21, 22]. Nevertheless, some firms would like to use the single rollover strategy in operations management. Thus, Liu et al. [23] and Yuan et al. [15] included a single rollover strategy in their consideration of limited trade-in duration. Unlike the above two studies, we consider the following aspects: (i) they all discuss the trade-in pricing strategy of traditional functional products, whereas we consider the trade-in pricing strategy of both fuel vehicles and NEVs. (ii) They did not consider the impact of the consumer's heterogeneous behavior on the trade-in pricing strategy, whereas we discuss the impact of the above factor on the trade-in pricing strategy of both fuel vehicles and NEVs.

With the rapid development of information technology, customers are becoming increasingly heterogeneous in their decision-making. Some literature has analyzed the impact of customers' heterogeneous behavior on trade-in pricing decisions for traditional functional products. For example, Sheu and Choi [19] analyzed the impact of customers' heterogeneous behavior on firms' preannounce pricing strategy. Liu et al. [23] analyzed firms' dynamic pricing strategy when they are faced with heterogeneous customers. However, all of the above studies have only analyzed the effect of consumers' heterogeneous behavior on the trade-in pricing strategy of traditional functional products. In contrast, this paper discusses the optimal pricing strategy for automobile producers under the condition of the consumer's heterogeneous behavior and the single rollover strategy.

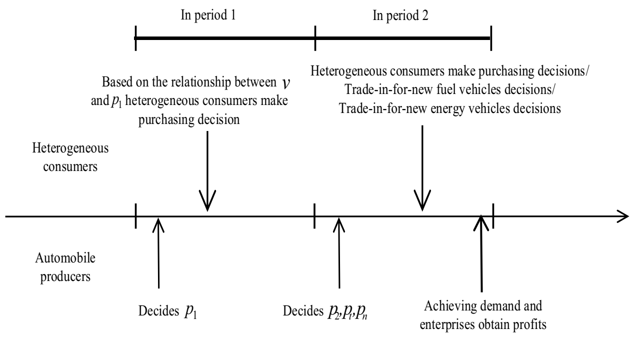
## 3. Model Description

In this section, we consider the automobile supply chain system that includes the automobile producer and heterogeneous consumers, and a two-stage dynamic game model is built between them. The automobile producer adopts the single rollover strategy to realize the replacement of the fuel vehicles (i.e., in Period 1, the old generation fuel vehicles $A_1$ are sold to heterogeneous consumers at selling price $p_1$; in Period 2, the new-generation fuel vehicles $A_2$ are sold to heterogeneous consumers at selling price $p_2$, however, when the new-generation fuel vehicles $A_2$ launch in the market, the old-generation fuel vehicles $A_1$ stopped being sold). At the same time, in Period 2, the NEVs $A_n$ are sold to heterogeneous consumers at selling price$p_n$. At the beginning of Period 2, to maintain old consumers and encourage them to make repeated purchases, automobile producers provide replacement consumers with trade-in-for-new fuel vehicles and trade-in-for-NEVs simultaneously. Thus, the replacement consumers can purchase $A_2$ with price $p_2 - p_t$, or they can purchase $A_n$ with price $p_n - p_t$, where $p_t$ ($0 \le p_t \le p_2$ and $0 \le p_t \le p_n$) is the trade-in rebate offered by the automobile producer to the replacement consumers. We assume that $A_1$ and $A_2$ have the same unit production cost c ($c \le p_1$ and $c \le p_2$) [23–26]. The unit production cost of $A_n$ is $c_n$ ($c_n \le p_n$).

Assume that all consumers are heterogeneous consumers and arrive at the market at the beginning of Period 1, and the market size is normalized as 1 [15, 23]. It is assumed that the heterogeneous consumers' willingness to pay for $A_1$ is $v$, which follows a uniform distribution in $[0, 1]$, and the willingness to pay for $A_2$ is$(1+\theta)v$ [23, 24]. In addition, in Period 2, heterogeneous consumers have different degrees of psychological acceptance of new-generation fuel vehicles and new-generation energy vehicles and are willing to pay different prices. The consumers' willingness to pay for new-generation energy vehicles is $(1+\gamma)v$, where $\gamma$ is the psychological acceptance degree of heterogeneous consumers to NEVs, where $\gamma \in (0, 1)$ and $\gamma\theta$.

Figure 1 illustrates the decision order of the automobile producer under the dynamic pricing strategy. On the one hand, at the beginning of Period 1, the automobile producer decides $p_1$, and at the beginning of Period 2, the automobile producer decides $p_2$, $p_t$, and $p_n$ to maximize their own total profit. On the other hand, for a given selling price $p_1$, heterogeneous consumers make purchase decisions by comparing the relationship between $p_1$ and $v$. At the

**Figure 1**
**Game order under the dynamic pricing strategy**




beginning of Period 2, heterogeneous consumers who have bought $A_1$ should decide whether to participate in trade-in-new fuel vehicles, participate in trade-in-for-NEVs, or continue to use old fuel vehicles. Heterogeneous consumers who have not bought $A_1$ should decide whether to buy $A_2$ or to buy $A_n$ or not to buy anything. Table 1 describes the parameters used in this subsection.

**Table 1**
**The parameters and explanations**

| Parameters | Descriptions |
|---|---|
| $A_i$ | Successive-generation fuel car, where $i \in \{1, 2\}$, 1 represents the old generation fuel cars, and 2 represents the new-generation fuel cars |
| $A_n$ | New energy vehicles |
| $v$ | The customers' valuation of $A_1$ |
| $c$ | The production cost of two generation fuel cars |
| $c_n$ | The production cost of new energy vehicles |
| $\gamma$ | The psychological acceptance degree of heterogeneous consumers to new energy vehicles |
| $\theta$ | The innovation incremental value of the second-generation new fuel vehicle over the first-generation new fuel vehicle |
| $s$ | The residual value of the $A_1$ |
| $\alpha$ | Primary consumers |
| $1-\alpha$ | Replacement consumers |
| $\delta$ | The durability of the $A_1$ |
| $q_{1B}$ | Number of customers who will purchase $A_1$ in Period 1 |
| $q_{2B}$ | Number of customers who will purchase $A_2$ in Period 2 |
| $q_{2Bn}$ | Number of customers who will purchase $A_n$ in Period 2 |
| $q_{2T}$ | Number of customers who participate in trade-in for $A_2$ in Period 2 |
| $q_{2Tn}$ | Number of customers who participate in trade-in for $A_n$ in Period 2 |
| $p_1$ | The selling price of $A_1$ |
| $p_2$ | The selling price of $A_2$ |
| $p_n$ | The selling price of $A_n$ |
| $p_t$ | The trade-in rebate |
| $\pi_2$ | The automobile producer's profit in Period 2 |
| $\pi_t$ | The total profit of the automobile producer in either period |

## 4. Dynamic Pricing Strategy

### 4.1. The choice behavior of heterogeneous consumers

In this section, heterogeneous consumers are divided into two groups: the first group is called primary consumers, and the second group is called replacement consumers. The proportion of the two groups of heterogeneous consumers is $\alpha$ and $1-\alpha$, respectively. We should analyze the demand function under different choices.

1) The demand function of the primary consumers. The primary consumers face two different choices: purchase the first-generation fuel vehicles or not (waiting until Period 2). The consumer utility in the above two different situations is $\mu_{nf} = v - p_1$ and 0, respectively, i.e., $p_1 \leq v$.

When $\mu_{nf} > 0$, the primary consumers choose to buy new fuel vehicles, and we can obtain the demand as

$$q_{1B} = \alpha \int_{p_1}^{1} 1dv = \alpha(1-p_1) \tag{1}$$

2) The demand function of the replacement consumers. In Period 1, the replacement consumers who have purchased fuel vehicles will also face three different choices. They can choose to participate in trade-in-for-new fuel vehicles, they can choose to take part in trade-in-for-NEVs, or they can select to continue using old fuel vehicles. The consumer utility under the above three different choices is $\mu_{tf} = (1+\theta)v - (p_2 - p_t)$,

$\mu_{tn} = (1+\gamma)v - (p_n - p_t)$, and $\mu_u = \delta v$, i.e., $p_2 - p_t \leq (1+\theta)v$, $p_n - p_t \leq (1+\gamma)v$.

When it satisfies the condition that $\mu_{tf} > \mu_{tn}$ and $\mu_{tf} > \mu_u$, the replacement consumers can choose trade-in-for-new fuel vehicles, and we can obtain that:

$$q_{2T} = (1-\alpha) \int_{\frac{p_2-p_t}{1+\theta-\delta}}^{\frac{p_2-p_n}{\gamma-\theta}} 1dv = (1-\alpha)\left(\frac{p_2-p_n}{\gamma-\theta} - \frac{p_2-p_t}{1+\theta-\delta}\right) \tag{2}$$

When it satisfies the condition that $\mu_{tn} > \mu_{tf}$ and $\mu_{tn} > \mu_u$, the replacement consumers can choose trade-in-for-NEVs, and we can obtain that:

$$q_{2Tn} = (1-\alpha) \int_{\frac{p_2-p_n}{\gamma-\theta}}^{1} 1dv = (1-\alpha)\left(1 - \frac{p_2-p_n}{\gamma-\theta}\right) \tag{3}$$

When it satisfies the condition that $\mu_{nf} < 0$ and $\mu_{2B} > \mu_{2Bn}$, the primary consumers who choose to wait in Period 1 will choose to buy the new-generation fuel vehicles in Period 2, and we can obtain that:

$$q_{2B} = \alpha \int_{0}^{\frac{p_2-p_n}{\gamma-\theta}} 1dv = \alpha\left(\frac{p_2-p_n}{\gamma-\theta}\right) \tag{4}$$

When it satisfies the condition that $\mu_{nf} < 0$ and $\mu_{2Bn} > \mu_{2B}$, the primary consumers who choose to wait in Period 1 will choose to buy the new-generation energy vehicles in Period 2, and we can obtain the following:

$$q_{2Bn} = \alpha \int_{\frac{p_2-p_n}{\gamma-\theta}}^{p_1} 1dv = \alpha\left(p_1 - \frac{p_2-p_n}{\gamma-\theta}\right) \tag{5}$$

## 4.2. Dynamic pricing strategy of the automobile producer

In this section, we analyze the automobile producer's dynamic pricing strategy. First, in Period 2, the automobile producer should decide the selling price of the second-generation fuel vehicles $p_2$, the selling price of NEVs $p_n$, and trade-in rebate $p_t$, so that it can maximize the automobile producer's profit in Period 2 as follows:

$$\underset{p_2,p_n,p_t}{Max} \quad \pi_2 = (p_2 - c)\,q_{2B} + (p_n - c_n)q_{2Bn} + (p_2 - p_t - c + s)q_{2T} + (p_n - p_t - c_n + s)q_{2Tn}$$

$$S.t.\begin{cases} q_{2B} \geq 0 \\ q_{2Bn} \geq 0 \\ q_{2T} \geq 0 \\ q_{2Tn} \geq 0 \\ p_t \leq p_2 \\ p_t \leq p_n \end{cases}$$

The above constraints can effectively ensure the nonnegativity and rationality of the selling prices and quantities. Specifically, the first four constraints can effectively guarantee the nonnegativity of two kinds of products in Period 2. The fifth and sixth constraints can effectively ensure that heterogeneous consumers can obtain a certain trade-in rebate when they choose trade-in programs, but it is not higher than the selling price of new products. Otherwise, automobile producers have no incentive to provide heterogeneous consumers with trade-in services.

According to the different choice behaviors of heterogeneous consumers in Period 2 and the decision-making behaviors of the automobile producer in Period 2, we can further obtain the total profit of the automobile producer in two periods as follows:

$$\underset{p_1}{Max} \quad \pi_t = (p_1 - c)\,q_{1B} + \pi_2^*$$

Next, we will discuss the dynamic pricing strategy of the automobile producer. The following Proposition 1 and Table A1 can be obtained by solving the above model according to the Kuhn-Tucker conditions (KKT) method.

**Proposition 1**. The optimal pricing decision when the dynamic pricing strategy is adopted by the automobile producer is shown as follows:

1) When the condition that $c_n > 1 + s - \gamma + \theta$, $c_n < \gamma + \theta + c$ and $c > 1 + s$, the automobile producer will not provide heterogeneous consumers with a trade-in program. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers will buy second-generation fuel vehicles, while some of them will purchase NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{3}(1 + 2c)$, $p_2 = \frac{1}{3}(2 + 3c)$, $p_n = \frac{1}{3}(2\theta + \gamma + c_n + 2)$, and $p_t = \frac{1}{3}(2\theta + \gamma + c + c_n + s)$.
2) When it satisfies the condition that $c_n > 1 + \theta + c$ and $c > 1 + s - \gamma$, the automobile producer will no longer provide heterogeneous consumers with trade-in service. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers will only purchase the second-generation new fuel vehicles. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1 + c)$, $p_2 = \frac{1}{3}(1 + 2c)$, $p_n = \frac{1}{3}(\theta + 2\gamma + 2c_n + 1)$, $p_t = \frac{1}{3}(\theta + \gamma + 2c + s)$.
3) When it satisfies the condition that

$$c_n > 1 + s - \gamma + \theta,\ c_n < 1 + (1 + \theta)c \text{ and } c > 1 + s + \theta$$

the automobile producer will no longer provide heterogeneous consumers with trade-in services. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers will only purchase the NEVs. The optimal decision is that $p_1 = \frac{1}{6}\ (1 + c)$, $p_2 = \frac{1}{3}(1 + 2c)$, $p_n = \frac{1}{3}(\theta + 2\gamma + 2c_n + 1)$, $p_t = \frac{1}{3}(\theta + \gamma + 2c + s)$.

4) When it satisfies the condition that $c_n < 1 + \theta + c$ and $c > 1 + \theta$, the automobile producer only provides trade-in-for-NEVs to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers purchase second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1 + c)$, $p_2 = \frac{1}{3}(1 + 2c)$, $p_n = \frac{1}{3}(\theta + \gamma + c_n + 2)$, and $p_t = \frac{1}{3}(\theta + \gamma + c + s)$.
5) When it satisfies the condition that $c_n > 1 + \theta + c$ and $c > -1 + s$, the automobile producer only provides trade-in-for-NEVs to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers will only purchase second-generation fuel vehicles. Thus, the optimal decision is that: $p_1 = \frac{1}{6}(1 + c)$, $p_2 = \frac{1}{3}(1 + 2c)$, $p_n = \frac{1}{3}(\theta + \gamma + c_n + 2)$, and $p_t = \frac{1}{3}(\theta + \gamma + 2c + s)$.
6) When it satisfies the condition that $c_n > 1 + (1 + \theta)c$, $c_n < 1 + s + \gamma - \theta$, and $c < 1 + s - \gamma + \theta$, the automobile producer only provides trade-in-for-new fuel vehicles to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1 + 3c)$, $p_2 = \frac{1}{3}(1 + 2c)$, $p_n = \frac{1}{3}(1 + \theta + \gamma + c_n)$, and $p_t = \frac{s+\gamma}{3}$.
7) When it satisfies the condition that $c_n > 1 + s + \gamma - \theta$, $c_n < 1 + (1 + \theta)c$ and $c < 1 + s + \gamma$, the automobile producer only provides trade-in-for-new fuel vehicles to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1 + c)$, $p_2 = \frac{1}{3}(1 + 2c)$, $p_n = \frac{1}{3}(1 + \gamma + c_n)$, and $p_t = \frac{s+c+\gamma+2\theta}{3}$.
8) When it satisfies the condition that $c_n > 1 + (1 + \theta)c$, $c_n < 1 + \theta + c$, and $c > -1 + s + \gamma$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1 + 2c)$, $p_2 = \frac{1}{3}(2 + 3c + \theta)$, $p_n = \frac{1}{3}(2 + \theta + c_n)$, and $p_t = \frac{1}{3}(s + c + 2c_n)$.
9) When it satisfies the condition that $c_n > s\theta + (-1 + \gamma - \theta)c$ and $c > -1 + s + \theta$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some pri-

mary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that: $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{1+\theta+2c_n}{3}$, and $p_t = \frac{s+c+c_n-\gamma}{3}$.

10) When it satisfies the condition that $c_n < 1+\theta+c$ and $c > 1+s+\gamma$, the automobile producer only provides trade-in-for-NEVs for heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers purchase nothing. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{1+2c_n+2\theta}{3}$ and $p_t = \frac{s+c+2c_n+\theta}{3}$.
11) When it satisfies the condition that $c_n < -1+s-\theta$ and $c < 1-\theta$, the automobile producer only provides trade-in-for-new fuel vehicles for heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers only buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+2c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{2+2c_n+\theta}{3}$ and $p_t = \frac{c+2s+c_n+2\gamma}{3}$.
12) When it satisfies the condition that $c_n > 1+(1+\theta)c$, $c_n < 1+\theta+c$, and $c < -1+s$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers only buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1+c}{3}$, $p_2 = \frac{2+c+\theta}{3}$, $p_n = \frac{1+2c_n+\gamma}{3}$ and $p_t = \frac{c+2s+2+\gamma}{3}$.
13) When it satisfies the condition that $c_n > 1-\theta+c$ and $c < -1+s+\gamma$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers only buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+2c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{1+3c_n+\gamma}{3}$ and $p_t = \frac{2+c+2s+3\gamma}{3}$.

We can obtain the following conclusion from Proposition 1:

1) When it satisfies the condition that $c_n > 1+s-\gamma+\theta$ and $c > 1+s+\theta$, in Period 2, the optimal selection strategy of the automobile producer is that he or she will not provide heterogeneous consumers with trade-in-for-new fuel vehicles, nor will he or she offer heterogeneous consumers with trade-in-for-NEVs. In this case, because the production cost of new-generation fuel vehicles and new-generation energy vehicles is very high, the automobile producer only provides relatively low trade-in rebates to heterogeneous consumers, and the selling price of new-fuel vehicles and new-energy vehicles is also very high, so they cannot attract consumers to participate in trade-in activity. In recent years, government subsidies for NEVs have become much smaller. As a result, heterogeneous consumers have higher costs to buy NEVs. Therefore, the optimal choice strategy for the automobile producer is not to provide the trade-in service. In Period 1, some primary consumers will choose to buy the first-generation new fuel vehicles, while others will wait.
2) When it satisfies the condition that $c_n < 1+\theta+c$ and $c > 1+s+\gamma$, in Period 2, the optimal selection strategy of the automobile producer is only to provide the trade-in-for-NEVs to heterogeneous consumers. In this case, the unit production cost of NEVs is relatively low, while the unit production cost of new fuel vehicles is relatively high. However, the trade-in rebate provided by automobile producers to replacement consumers is relatively low. Meanwhile, the replacement consumers will also buy NEVs at a lower cost. In Period 1, some primary consumers will choose to buy the first-generation new fuel vehicles, while others will wait.
3) When it satisfies the condition that $c_n > 1+(1+\theta)c$, $c_n < 1+s+\gamma-\theta$, and $c < 1+s+\gamma$, in Period 2, the optimal choice strategy of the automobile producer is to directly sell new fuel vehicles or NEVs to the primary consumers or to provide replacement consumers with trade-in-for-new fuel vehicles. However, automobile producers will not provide replacement consumers with trade-in-NEVs. In this case, the unit production cost of NEVs will sometimes be very high, which means that the automobile producer will choose not to provide trade-in-for-NEV service. On the other hand, the unit production cost of new fuel vehicles is low, so replacement consumers will buy new fuel vehicles at a lower price, and automobile producers will directly sell new fuel vehicles to heterogeneous consumers or provide trade-in-for-new fuel vehicles. In Period 1, some primary consumers will choose to buy the first-generation new fuel vehicles, while others will wait.

## 5. Preannounce Pricing Strategy

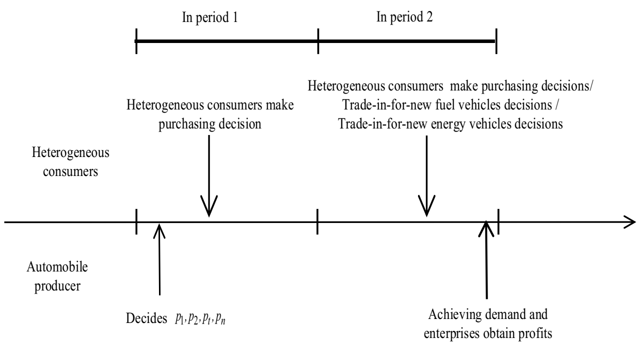
### 5.1. The choice behavior of heterogeneous consumers

In this section, we continue to consider the automobile supply chain system, which includes automobile producers and heterogeneous consumers, and a two-stage dynamic game model is built between them. We assume that all consumers are heterogeneous consumers in the market and arrive at the beginning of Period 1, and all the heterogeneous consumers are normalized as 1 in the market. Figure 2 illustrates the decision order under the preannounce pricing strategy.

On the one hand, at the beginning of Period 1, the automobile producer decides $p_1, p_2, p_t$, and $p_n$ to maximize the total profit. On the other hand, for a given selling price $p_1, p_2, p_t$, and $p_n$, at the beginning of Period 1, the heterogeneous consumer makes a purchasing decision. At the beginning of Period 2, the heterogeneous consumer makes a purchase decision, a trade-in-for-new vehicles decision, or a trade-in-for-NEVs decision.

When the automobile producer adopts the preannounce pricing strategy, the consumer utility obtained by heterogeneous consumers who do not buy any products in either period is $U_{NN} = 0$. The consumer utility obtained by heterogeneous consumers who do not buy $A_1$ but buy $A_2$ is $U_{NA2} = 0 + (1+\theta)v - p_2$. The consumer utility

**Figure 2**
**The decision order under the preannounce pricing strategy**



obtained by heterogeneous consumers who do not buy $A_1$ but buy $A_n$ is $U_{NAn} = 0 + (1+\gamma)v - p_n$. The consumer utility obtained by heterogeneous consumers who have bought $A_1$ and continue to use it is $U_{A1N} = v - p_1 + v$. The consumer utility obtained by heterogeneous consumers who have bought $A_1$ and participate in the trade-in-new fuel vehicles is $U_{A1A2} = v - p_1 + (1+\theta)v - p_2 + p_t - s$. The consumer utility obtained by heterogeneous consumers who have bought $A_1$ and participate in the trade-in-NEVs is $U_{A1AN} = v - p_1 + (1+\gamma)v - p_n + p_t - s$.

## 5.2. Preannounce pricing strategy of the automobile producer

Next, we analyze the optimal pricing decision when the automobile producer adopts the preannounce pricing strategy. First, at the beginning of Period 1, the automobile producer sets selling prices $p_1$, $p_2$, $p_t$, and $p_n$. Then, the heterogeneous consumers make purchase decisions. Thus, the total profit of the automobile producer in two periods is

$$\underset{p_1,p_2,p_n,p_t}{Max}\ \pi_t = (p_1 - c)q_{1B} + (p_2 - c)q_{2B} + (p_n - c_n)q_{2Bn} + (p_2 - p_t - c + s)q_{2T} + (p_n - p_t - c_n + s)q_{2Tn}$$

$$S.t.\begin{cases} q_{1B} \geq 0 \\ q_{2B} \geq 0 \\ q_{2Bn} \geq 0 \\ q_{2T} \geq 0 \\ q_{2Tn} \geq 0 \\ p_t \leq p_2 \\ p_t \leq p_n \end{cases}$$

The above constraints can effectively ensure the nonnegativity and rationality of the selling prices and quantities. Specifically, the first four constraints can effectively guarantee the nonnegativity of two kinds of products in Period 2. The fifth and sixth constraints can effectively ensure that heterogeneous consumers can obtain a certain trade-in rebate when they choose a trade-in program, but it is not higher than the selling price of new products. Otherwise, the automobile producer has no incentive to provide heterogeneous consumers with trade-in service.

Then, we will discuss the preannounce pricing strategy of the automobile producer. The following Proposition 2 and Table A2 can be obtained by solving the above model according to the Kuhn-Tucker conditions (KKT) method.

**Proposition 2**. The optimal pricing decision when the preannounce pricing strategy is adopted by the automobile producer is shown as follows:

1) When it satisfies the condition, $c_n > 1 + s - \gamma + \theta$, $c_n < \gamma + \theta + c$, and $c > 2 + s$, the automobile producer will not provide heterogeneous consumers with a trade-in program. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers will buy second-generation fuel vehicles, while some of them will buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+2c)$, $p_2 = \frac{1}{6}(2+5c)$, $p_t = \frac{1}{3}(3\theta + \gamma + c + c_n + 2s)$, and $p_n = \frac{1}{3}(3\theta + 2\gamma + c_n + 3)$.
2) When it satisfies the condition that $c_n > 1 + \theta + c$ and $c > 1 + s - \gamma$, the automobile producer will no longer provide heterogeneous consumers with trade-in service. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers will only buy the second-generation new fuel vehicles. Thus, the optimal decision is that: $p_1 = \frac{1}{6}(1+3c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{1}{3}(2\theta + \gamma + 3c_n + 1)$, and $p_t = \frac{1}{6}(3\theta + \gamma + 2c + s)$.
3) When it satisfies the condition that $c_n > 2 + s - \gamma + \theta$ and $c > 1 + s + \theta$, the automobile producer will no longer provide heterogeneous consumers with trade-in service. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers will only buy the NEVs. The optimal decision is that $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{1}{3}(2\theta + \gamma + c_n + 2)$, and $p_t = \frac{1}{3}(2\theta + 2\gamma + 2c + s)$.
4) When it satisfies the condition that $c_n < 2 + \theta + c$ and $c > 2 + \theta$, the automobile producer only provides trade-in-for-NEVs to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(2+c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{1}{3}(2\theta + \gamma + c_n + 1)$, and $p_t = \frac{1}{3}(2\theta + 2\gamma + c + s)$.
5) When it satisfies the condition that $c_n > 2 + \theta + c$ and $c > -1 + s$, the automobile producer only provides trade-in-for-NEVs to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers will only buy the second-generation fuel vehicles. Thus, the optimal decision is that: $p_1 = \frac{1}{6}(2+3c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{1}{3}(2\theta + 2\gamma + c_n + 1)$, and $p_t = \frac{1}{3}(2\theta + 2\gamma + 2c + s)$.
6) When it satisfies the condition that $c_n > 1 + (1+\theta)c$ and $c < 1 + s - \gamma + \theta$, the automobile producer only provides trade-in-for-new fuel vehicles to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{1}{3}(2+2c)$, $p_n = \frac{1}{3}(2 + 2\theta + \gamma + c_n)$, and $p_t = \frac{2s+\gamma}{3}$.
7) When it satisfies the condition that $c_n > 2 + s + \gamma - \theta$ and $c < 1 + s + \gamma$, the automobile producer only provides trade-in-for-new fuel vehicles to heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that: $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{1}{3}(2 + \gamma + c_n)$, and $p_t = \frac{2s+c+2\gamma+\theta}{3}$.
8) When it satisfies the condition that $c_n > 2 + (1+\theta)c$ and $c > -1 + s + \gamma$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1 + 2c + \theta)$, $p_2 = \frac{1}{3}(3 + 3c + \theta)$, $p_n = \frac{1}{3}(2 + 2\theta + c_n)$, and $p_t = \frac{1}{3}(2s + c + 2c_n)$.
9) When it satisfies the condition that $c_n > s\theta + (2 + \gamma - \theta)c$ and $c > 1 + s + \theta$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, some primary consumers

buy second-generation fuel vehicles, and some of them buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{2+\theta+2c_n}{3}$, and $p_t = \frac{2s+c+c_n-\gamma}{3}$.

10) When it satisfies the condition that $c_n < 2+\theta+c$ and $c > 1+s+\gamma$, the automobile producer only provides trade-in-for-NEVs for heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers purchase nothing. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+2c)$, $p_2 = \frac{1}{3}(1+2c)$, $p_n = \frac{2+2c_n+2\theta}{3}$ and$p_t = \frac{2s+c+2c_n+\theta}{3}$.
11) When it satisfies the condition that $c_n < 1+s-\theta$ and $c < 1-\theta$, the automobile producer only provides trade-in-for-new fuel vehicles for heterogeneous consumers. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers only buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{2+2c_n+2\theta}{3}$, and $p_t = \frac{2c+2s+c_n+2\gamma}{3}$.
12) When it satisfies the condition that $c_n > 2+(1+\theta)c$ and $c < 1+s$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers only buy NEVs. Thus, the optimal decision is that: $p_1 = \frac{1+c+\theta}{6}$, $p_2 = \frac{2+2c+\theta}{3}$, $p_n = \frac{2+2c_n+\gamma}{3}$, and $p_t = \frac{2+2c+2s+\gamma}{3}$.
13) When it satisfies the condition that $c_n > 2-\theta+c$ and $c < 1+s+\gamma$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, some primary consumers will buy the first-generation fuel vehicles, and some of them will wait. In Period 2, the primary consumers only buy NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(1+c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{2+3c_n+2\gamma}{3}$, and $p_t = \frac{2+2c+2s+2\gamma}{3}$.
14) When it satisfies the condition that $c_n > 1-\theta+c$ and $c < 1+2s+\gamma$, the automobile producer can not only provide trade-in-for-new fuel vehicles for heterogeneous consumers but also offer trade-in-for-NEVs to them. In Period 1, the primary consumers will not buy the first-generation fuel vehicles. In Period 2, the primary consumer only buys NEVs. Thus, the optimal decision is that $p_1 = \frac{1}{6}(2+c)$, $p_2 = \frac{2}{3}(1+c)$, $p_n = \frac{2+2c_n+2\gamma}{3}$, and $p_t = \frac{1+2c+2s+2\gamma}{3}$.

We can obtain the following conclusion from Proposition 2:

1) When it satisfies the condition that $c_n > 1+s-\gamma+\theta$ and $c > 1+s+\theta$, in Period 2, the optimal selection strategy of the automobile producer is that he or she will not provide heterogeneous consumers with trade-in-for-new fuel vehicles, nor will he or she offer heterogeneous consumers with trade-in-for-NEVs. In this case, because the production cost of new-generation fuel vehicles and new-generation energy vehicles is very high, the automobile producer only provides relatively low trade-in rebates to heterogeneous consumers, and the selling price of new-fuel vehicles and new-energy vehicles is also very high, so they cannot attract consumers to participate in trade-in activity. In recent years, government subsidies for NEVs have become much smaller. As a result, heterogeneous consumers have higher costs to buy NEVs. Therefore, the optimal choice strategy for the automobile producer is to not provide the trade-in service. In Period 1, some primary consumers will choose to buy the first-generation new fuel vehicles, while others will wait.
2) When it satisfies the condition that $c_n < 2+\theta+c$ and $c > 1+s+\gamma$, in Period 2, the optimal selection strategy of the automobile producer is only to provide the trade-in-for-NEVs to heterogeneous consumers. In this case, the unit production cost of NEVs is relatively low, while the unit production cost of new fuel vehicles is relatively high. However, the trade-in rebate provided by automobile producers to replacement consumers is relatively low. Meanwhile, the replacement consumers will also buy NEVs at a lower cost. In Period 1, some primary consumers will choose to buy the first-generation new fuel vehicles, while others will wait.
3) When it satisfies the condition that $c_n > 2+(1+\theta)c$, $c_n < 2+s+\gamma-\theta$, and $c < 1+s+\gamma$, in Period 2, the optimal choice strategy of the automobile producer is to directly sell new fuel vehicles or NEVs to the primary consumers or to provide replacement consumers with the trade-in-for-new fuel vehicles. However, automobile producers will not provide replacement consumers with trade-in-NEVs. In this case, the unit production cost of NEVs will sometimes be very high, which means that the automobile producer will choose not to provide trade-in-for-NEV service. On the other hand, the unit production cost of new fuel vehicles is low, so replacement consumers will buy new fuel vehicles at a lower price, and automobile producers will directly sell new fuel vehicles to heterogeneous consumers or provide trade-in-for-new fuel vehicles. In Period 1, some primary consumers will choose to buy the first-generation new fuel vehicles, while others will wait.
4) When it satisfies the condition that $c_n > 1+(1+\theta)c$, $c_n < 2+s+\gamma-\theta$, and $c < 1+s+\gamma$, in Period 2, the optimal choice strategy of the automobile producer is to directly sell new fuel vehicles or NEVs to the primary consumers or to provide replacement consumers with the trade-in-for-new fuel vehicles. However, the automobile producer will not provide replacement consumers with trade-in-for-NEVs. In this case, the unit production cost of NEVs will sometimes be very high, which means that the automobile producer will choose not to provide trade-in-for-NEV service. On the other hand, the unit production cost of new fuel vehicles is low, so replacement consumers will buy new fuel vehicles at a lower price, and the automobile producer will directly sell new fuel vehicles to heterogeneous consumers or provide trade-in-for-new fuel vehicles. In Period 1, the primary consumers will choose to wait.

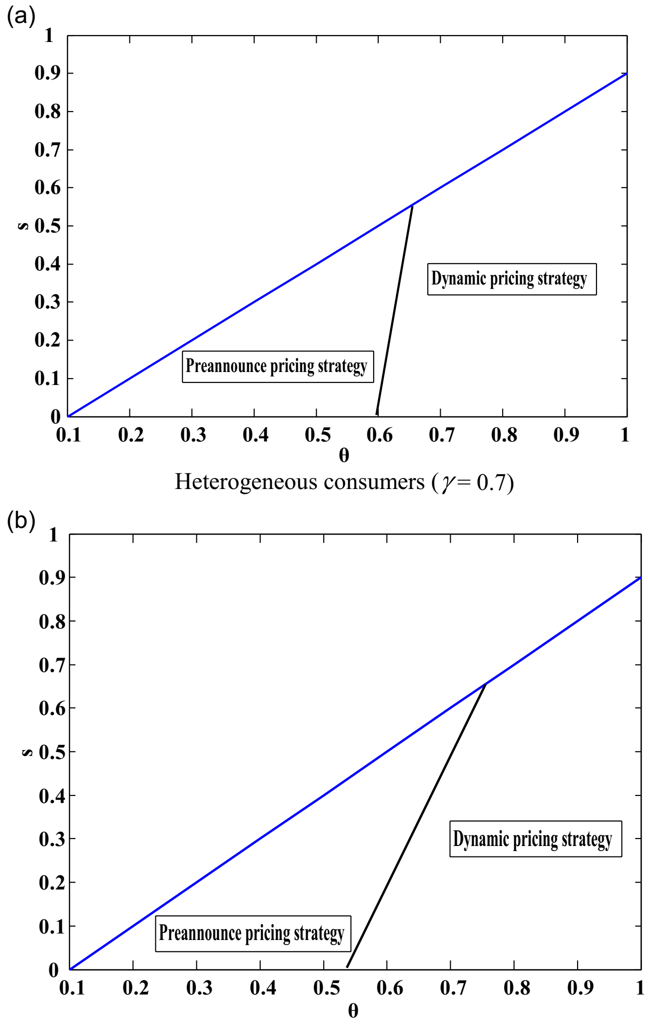
### 5.3. Optimal pricing strategy of the automobile producer

In this section, we can obtain the optimal pricing strategy of the automobile producer by comparing the profit of the automobile producer under the dynamic pricing strategy and the preannounce pricing strategy. When we consider the heterogeneous behavior of consumers, we can obtain Proposition 3 and Figure 3.

**Proposition 3**. When the automobile producer provides heterogeneous consumers with both trade-in-for-new fuel vehicles and trade-in-for-NEVs, there exists a threshold of the innovation incremental value of the second-generation new fuel vehicle over the first-generation new fuel vehicle (i.e., $\hat{\theta} \in \left[0, \frac{\gamma^2+2c}{2\gamma}\right]$). When it satisfies the condition $\theta > \hat{\theta}$, automobile producers should adopt the dynamics pricing strategy. In contrast, automobile producers should adopt the preannounce pricing strategy.

We find that when the heterogeneous behavior of consumers is strong and the innovation value of new-generation fuel vehicles is low, the automobile producer should choose the preannounce

**Figure 3**
**The optimal pricing strategy of the automobile producer**




(a) Heterogeneous consumers ($\gamma = 0.7$)

(b) Heterogeneous consumers ($\gamma = 0.5$)

pricing strategy. This is because it can alleviate the nibbling effect of the old-generation products on the new-generation products in the second period so that the automobile producer can obtain higher profits from the sales of the new-generation products. Otherwise, the automobile producer should adopt the dynamic pricing strategy.

## 6. Conclusions

In this study, we mainly analyze the effect of the consumer's heterogeneous behavior on the pricing strategy for the NEV producer. First, we consider a two-period game problem to decide the optimal selling prices of both two-generation new fuel vehicles and NEVs when the automobile producer adopts a dynamic pricing strategy. Then, we analyze a two-period game problem to determine the optimal selling prices of two generations of new fuel vehicles and NEVs when the automobile producer uses a preannounce pricing strategy. Finally, we can obtain the optimal pricing strategy of the automobile producer by comparing the dynamic pricing strategy with the preannounce pricing strategy.

We can obtain the following conclusions: (1) for heterogeneous consumers, their choice behavior is diverse. Specifically, in Period 1, some heterogeneous consumers can choose to purchase first-generation fuel vehicles, and others choose to wait. In Period 2, some primary heterogeneous consumers choose to purchase second-generation fuel vehicles, some consumers choose to purchase NEVs, and some others choose to continue to use old-generation fuel vehicles. Some replacement heterogeneous consumers take part in trade-in-for-new fuel vehicles, and some of them choose to participate in trade-in-for-NEVs. (2) For the automobile producer, when choosing which kind of trade-in strategy to provide, the automobile producer should consider the production cost of new vehicles and the trade-in rebate. On the one hand, when the production cost is high but the trade-in rebate is very low, the automobile producer does not provide the trade-in service. On the other hand, the production cost of new vehicles is relatively low, but the trade-in rebate is very high, and automobile producers should provide trade-in services to heterogeneous consumers. (3) When the heterogeneous behavior of consumers is strong and the innovation value of new-generation fuel vehicles is low, the automobile producer should choose the preannounce pricing strategy. Otherwise, the automobile producer should adopt the dynamic pricing strategy.

Moreover, we can draw the following managerial insights: From the government's perspective: (1) the government should provide more subsidies for consumers who participate in the trade-in-for NEVs, reduce the cost of consumers to buy NEVs, and promote the enthusiasm of consumers to purchase. (2) The government should provide much more public services, such as building more charging piles, to reduce the cost of consumers using NEVs. From the enterprise's perspective: (1) the choice between different pricing strategies of NEV producers mainly depends on the innovation value of new-generation fuel vehicles. If the new generation of fuel vehicles is highly innovative, a dynamic pricing strategy should be chosen. In contrast, the preannounce pricing strategy should be selected. (2) To better promote the development of NEVs, when facing heterogeneous consumers, on the one hand, energy vehicle producers should provide more subsidies for consumers to participate in the trade-in for new vehicles to reduce the cost for consumers to buy NEVs. On the other hand, energy vehicle producers should continue to improve the innovation level of new-generation fuel vehicles and at the same time continue to enhance the durability of NEVs to meet the needs of different consumers and maximize the profits of energy vehicle producers. From the consumers' perspective: (1) consumers should actively participate in the trade-in-for NEVs and purchase NEVs at a lower cost. (2) Consumers should consider the pricing strategy of the enterprise comprehensively and choose the chance to participate in the trade-in-for NEVs.

This paper discusses pricing strategies for a NEV producer considering the consumer's heterogeneous behavior. In the future, we will discuss the following questions. First, if the government provides subsidies to consumers, how do consumers change their purchase behavior? How does the automobile producer make corresponding pricing decisions? Second, how does the automobile producer make pricing decisions when the firm sells new vehicles using online platforms? Third, how does the automobile producer change its pricing decision when the firm faces the second-hand market?

## Acknowledgement

We also thank the English editor on the AJE website who helped proofread and enhance the English presentation of this study.

## Funding Support

This work was supported by the Natural Science Foundation of University in Jiangsu Province (No. 22KJB630005), the Social

Science Foundation in Jiangsu Province (No. 22GLC011), the Philosophy and Social Science Research Project of University in Jiangsu Province (No. 2022SJYB1167 and No. 2020SJA1029), the Humanities and Social Sciences Fund of the Ministry of Education (No. 22YJC630148), and the National Natural Science Foundation of China (No. 72171103 and No. 72274083).

## Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

## Conflicts of Interest

Wenbo Li is an Editorial Board Member for *Green and Low-Carbon Economy*, and Lead Guest Editor of the special issue, and was not involved in the editorial review or the decision to publish this article. The authors declare that they have no conflicts of interest to this work.

## Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

## Author Contribution Statement

**Xiaoqing Zhang:** Conceptualization, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Xigang Yuan:** Conceptualization, Methodology, Software, Validation, Data curation, Writing – original draft, Visualization, Project administration. **Wenbo Li:** Validation, Supervision, Funding acquisition. **Yongjian Wang:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

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**How to Cite:** Zhang, X., Yuan, X., Li, W., & Wang, Y. (2024). Research on the Trade-In Pricing Strategy of New Energy Vehicle Producers Considering the Consumers' Heterogeneous Behavior. *Green and Low-Carbon Economy*, *2*(4), 219–230. https://doi.org/10.47852/bonviewGLCE32021036

## Appendices

**Table A1**
**Biofuel production routes for food security**

| | | In Period 1 | In Period 2 | | | |
|---|---|---|---|---|---|---|
| Case | Condition | Purchase new fuel vehicles | Purchase new fuel vehicles | Purchase new energy vehicles | Trade-in-for-new fuel vehicles | Trade-in-for-new energy vehicles |
| 1 | $c_n > 1 + s - \gamma + \theta$, $c_n < \gamma + \theta + c$, $c > 1 + s$ | Yes | Yes | Yes | No | No |
| 2 | $c_n > 1 + \theta + c$, $c > 1 + s - \gamma$ | Yes | Yes | No | No | No |
| 3 | $c_n > 1 + s - \gamma + \theta$, $c_n < 1 + (1 + \theta)c$, $c > 1 + s + \theta$ | Yes | No | Yes | No | No |
| 4 | $c_n < 1 + \theta + c$, $c > 1 + \theta$ | Yes | Yes | Yes | No | Yes |
| 5 | $c_n > 1 + \theta + c$, $c > -1 + s$ | Yes | Yes | No | No | Yes |
| 6 | $c_n > 1 + (1 + \theta)c$, $c_n < 1 + s + \gamma - \theta$, $c < 1 + s - \gamma + \theta$ | Yes | Yes | Yes | Yes | |
| 7 | $c_n > 1 + s + \gamma - \theta$, $c_n < 1 + (1 + \theta)c$, $c < 1 + s + \gamma$ | Yes | Yes | Yes | Yes | |
| 8 | $c_n > 1 + (1 + \theta)c$, $c_n < 1 + \theta + c$, $c > -1 + s + \gamma$ | Yes | Yes | Yes | Yes | Yes |
| 9 | $c_n > s\theta + (-1 + \gamma - \theta)c$, $c > -1 + s + \theta$ | Yes | Yes | Yes | Yes | Yes |
| 10 | $c_n < 1 + \theta + c$, $c > 1 + s + \gamma$ | Yes | No | No | No | Yes |
| 11 | $c_n < -1 + s - \theta$, $c < 1 - \theta$ | Yes | No | Yes | Yes | No |
| 12 | $c_n > 1 + (1 + \theta)c$, $c_n < 1 + \theta + c$, $c < -1 + s$ | Yes | | | Yes | Yes |
| 13 | $c_n > 1 - \theta + c$, $c < -1 + s + \gamma$ | Yes | No | Yes | Yes | Yes |

**Table A2**
**The automobile producer's optimal decision under the preannouncement pricing strategy**

| | | In Period 1 | In Period 2 | | | |
|---|---|---|---|---|---|---|
| Case | Condition | Purchase new fuel vehicles | Purchase new fuel vehicles | Purchase new fuel vehicles | Trade-in-for-new fuel vehicles | Trade-in-for-new energy vehicles |
| 1 | $c_n > 1 + s - \gamma + \theta$, $c_n < \gamma + \theta + c$, $c > 2 + s$ | Yes | Yes | Yes | No | No |
| 2 | $c_n > 1 + \theta + c$, $c > 1 + s - \gamma$ | Yes | Yes | No | No | No |
| 3 | $c_n > 2 + s - \gamma + \theta$, $c_n < 1 + (1 + \theta)c$, $c > 1 + s + \theta$ | Yes | No | Yes | No | No |
| 4 | $c_n < 2 + \theta + c$, $c > 2 + \theta$ | Yes | Yes | Yes | No | Yes |
| 5 | $c_n > 2 + \theta + c$, $c > -1 + s$ | Yes | Yes | No | No | Yes |
| 6 | $c_n > 1 + (1 + \theta)c$, $c_n < 2 + s + \gamma - \theta$, $c < 1 + s - \gamma + \theta$ | Yes | Yes | Yes | Yes | |
| 7 | $c_n > 2 + s + \gamma - \theta$, $c_n < 1 + (1 + \theta)c$, $c < 1 + s + \gamma$ | Yes | Yes | Yes | Yes | |
| 8 | $c_n > 2 + (1 + \theta)c$, $c_n < 1 + \theta + c$, $c > -1 + s + \gamma$ | Yes | Yes | Yes | Yes | Yes |
| 9 | $c_n > s\theta + (2 + \gamma - \theta)c$, $c > 1 + s + \theta$ | Yes | Yes | Yes | Yes | Yes |
| 10 | $c_n < 2 + \theta + c$, $c > 1 + s + \gamma$ | Yes | No | No | No | Yes |
| 11 | $c_n < 1 + s - \theta$, $c < 1 - \theta$ | Yes | No | Yes | Yes | No |
| 12 | $c_n > 2 + (1 + \theta)c$, $c_n < 2 + \theta + c$, $c < 1 + s$ | Yes | | | Yes | Yes |
| 13 | $c_n > 2 - \theta + c$, $c < 1 + s + \gamma$ | Yes | No | Yes | Yes | Yes |
| 14 | $c_n > 1 - \theta + c$, $c < 1 + 2s + \gamma$ | No | No | Yes | Yes | Yes |