

## IMPACT OF SUBSIDY PHASE-OUT AND CREDIT TRADING POLICY TOOLS ON THE COMPETITIVE STRATEGIES OF CHINESE PASSENGER CAR ENTERPRISES

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**Abstract.** In the context of subsidy phase-out and the tightening of credit trading policy tools, enterprises producing internal combustion engine passenger cars have also started to produce new energy passenger cars, creating a competitive market with new energy passenger car enterprises. To explore the operation strategies and profit fluctuations of two enterprises in passenger car market and credit trading market, this paper develops a duopoly competition game model. Based on solving a multi-objective equilibrium problem, and performing numerical simulations with real data on Chinese passenger car market, this paper analyzes the interactive impact of policy tools on market competition. The conclusions point out that the numerical relationship between the price of positive new energy credits and credit deficit penalty is decisive to enterprises' pricing strategies. As the subsidy recedes, the competitiveness of new energy passenger car enterprise will decline. The policy tools at corporate average fuel consumption credit regulation level only have a negative interactive effect on hybrid energy passenger car enterprise's pricing and production strategy. There is a threshold for the difference between corporate average fuel consumption up-to-standard value and actual value, below which hybrid energy passenger car enterprise will produce more new energy passenger cars than internal combustion engine passenger cars. The tightening of policy tools at new energy credit regulation level will drive both enterprises to raise price and reduce yield.

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### 1. INTRODUCTION

The competition between new entry enterprises and existing enterprises has attracted wide attention from entrepreneurs and academics. New entrants have a greater incentive and ability to breakthrough innovation than existing enterprises [1]. The potential to achieve technological innovation [2] and technological breakthroughs [3] often gives new entrants the advantage of government policy support [4], but their limited managerial and financial resources [5] also cause a higher probability of failure [6]. When existing enterprises are unable to

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maintain their sales and technical advantages, new entrants will overtake existing enterprises to take the lead [7]. In the competition between new entrants and incumbents, strategies help enterprises to link their strengths and weaknesses with environmental opportunities and threats [8,9]. Scholars generally agree with Tirole [10] that pricing strategy is the main instrument for short-term competition between enterprises, while product selection and production strategy are the main instruments for medium-term competition. Therefore, in the context of competition between new entrants and existing enterprises, their pricing, product selection, and production strategies deserve in-depth study.

As NEEs enter passenger car market, they form significant competitive situation with existing passenger car enterprises. In response to the clear policy trend to encourage NE-PC<sup>1</sup> development, existing passenger car enterprises are gradually shifting from producing only ICE-PCs<sup>2</sup> to producing both ICE-PCs and NE-PCs [11], namely HEEs. The top 13 passenger car brands in China's ICE-PC market sales are all HEEs, and they account for 79.99% market share [12]. It can be seen that the top firms or even all ICE-PC automakers in China, have started to produce or introduce NE-PCs and transform into HEEs. Therefore, there are few enterprises producing ICE-PCs in China that have not yet transformed into HEEs. On one hand, both NEE and HEE produce NE-PCs, so there is price competition between them in NE-PC market. On the other hand, the substitution effect between NE-PCs and ICE-PCs [13] affects not only the competition between HEE and NEE, but also the product layout of HEE [14]. Therefore, in a competitive context, how passenger car enterprises improve their price advantage, plan their product layout and determine the optimal production are important issues to gain competitive advantage and ensure sustainable development.

Economic policies aimed at energy conservation and emission reduction such as NE-PC subsidy, fuel and CO<sub>2</sub> emission standards have been widely applied in passenger car industry [15]. Since 2009, China's passenger car market policy has undergone a change from subsidy launch, subsidy phase-out, and the gradual replacement of subsidy by *the Parallel Administration of the CAFC and NE Credits of Passenger Car Enterprises* (short for DCP), as shown in Figure 1. Among them, the subsidy for some NE-PCs such as battery electric vehicles will expire at the end of 2022 [16], while the subsidy for some cleaner NE-PCs such as fuel cell vehicles will continue [17]. In addition, the proposal to extend the NEV comprehensive subsidy policy until 2025 was presented at the People's Congress [18]. DCP includes two types of policy tools, one of which is aimed at urging energy efficiency and emission reduction of ICE-PCs, containing CAFC target calculating CAFC credit and credit deficit penalty which is a punishment for enterprises with credit deficit. The other type of policy tools contains NE-PC model credit standard and NE credit ratio quota, aiming to serve the market development of NE-PCs by accounting for NE credit. In line with DCP, positive NE credit can offset both negative CAFC credit and negative NE credit, and enterprises holding negative credits can avoid penalty by purchasing positive NE credits. The trading of positive NE credit has changed the profit structure of passenger car enterprises. According to the government announcement [19], there are 88 non-compliant HEEs with negative comprehensive credits, all of which need to purchase positive NE credits to avoid the production suspension penalty, such as the credits held by FAW-Volkswagen and SAIC-GM are -1,322,174 and -100,376, respectively. Twenty eight NEEs with zero CAFC credit and positive NE credits can sell positive NE credits to HEEs, such as the positive NE credits available for trading of Tesla and Xiaopeng are 860,358 and 110,310, respectively. Since the launch of credit trading policy in 2018, the total accumulated transaction is 9.95 million credits, the total amount is 14.1 billion CNY, and the total orders are 324. Among them, in 2020 [20] and 2021 [21], the transaction scales are 2.15 million credits and 5.24 million credits, the transaction amounts are 2.59 billion CNY and 10.94 billion CNY, the orders are 73 and 138, the average transaction prices are 1204 CNY per credit and 2088 CNY per credit respectively, and all showing a significant surge trend. Product choice theory states that economic factors are decisive for enterprises

<sup>1</sup>China standard "Terms and Definitions of Automobiles and Trailer Types" (GB/T 3730.1-2001) divides passenger vehicles into NE-PC and ICE-PC. NE-PC refers to the passenger vehicles using new power systems, completely or mainly driven by new energy sources, including plug-in hybrid (including extended range) passenger vehicles, pure-electric passenger vehicles, fuel cell passenger vehicles, and so on.

<sup>2</sup>ICE-PC refers to passenger vehicles other than NE-PCs and fueled with gasoline, diesel, gas fuel, or alcohol ether fuel, and so on (including non-plug-in hybrid passenger vehicles).

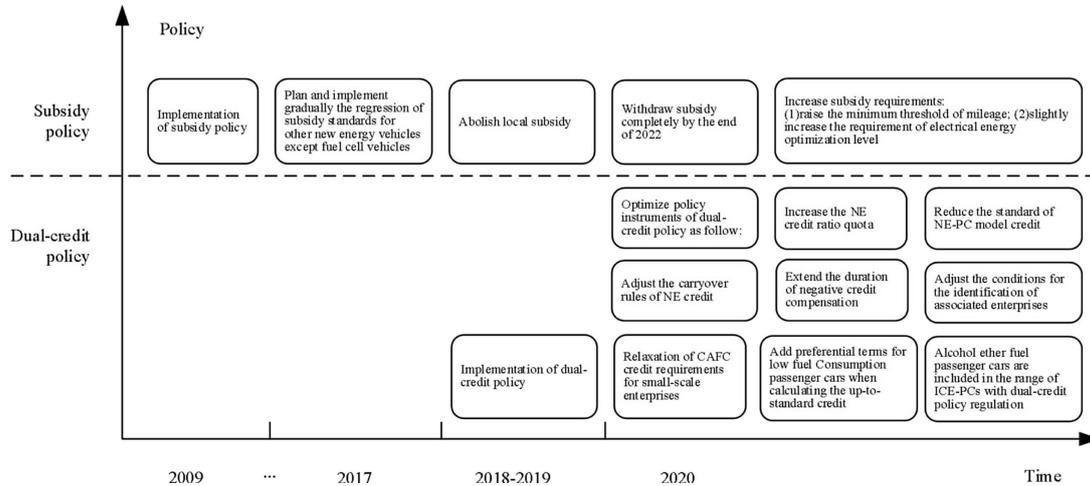


FIGURE 1. Policy changes at critical time points in Chinese passenger car industry.

to develop pricing and production strategies [22]. Therefore, with policy optimization constantly changing the profit structure of passenger car enterprises, how HEE and NEE can gain a sustainable competitive advantage is an urgent issue to be explored at present.

Based on the above discussion, this paper mainly explores three questions: (1) What are the optimal pricing and production strategies for HEE and NEE in the context of credit transactions changing the enterprises' profit structure? (2) How will HEE and NEE optimize their pricing and production strategies as the subsidy retreats and credit trading policy tools tightens, and does HEE show a green transformation trend? (3) Comparing the strategic trends of HEE and NEE during policy changes, which type of enterprises can gain competitiveness and achieve sustainable development?

The remainder of this research is configured as below. Section 2 conducts the theoretical background. Section 3 establishes the game model and derives the equilibrium solutions. Section 4 compares and presents sensitivity analysis of enterprises' optimal pricing and production strategies. Numerical simulations with real values are conducted in Section 5. The concluding results and practical implications are presented in Section 6.

## 2. THEORETICAL BACKGROUND

### 2.1. Brief background

To promote NE-PC shift from undersupply to large-scale production, China introduced subsidy policy in 2009 [23]. In an attempt to prevent over-reliance on subsidies [24] and to ease the high financial pressure [25], the subsidy is gradually declined since 2017. In 2018, China enacted a progressive replacement strategy for the subsidy with DCP, which drives a shift of financial pressure from the government to enterprises [25]. Common sense suggests that HEE already has a solid and long-term market base and will develop competitive strategies to curb NEE's entry. However, the derivative economic market spawned by credit trading policy tools drives HEE's demand for the credit product of NEE, providing a phase-in effective growth space for NEE. Therefore, rather than blocking NEE entry, HEE needs positive NE credit sold by NEE to avoid credit deficit penalty. Consequently, the above reasons motivate HEE's entry accommodation strategy for NEE. Accordingly, the competition between HEE and NEE is not only limited to passenger car sales market, but also behaves in the credit trading market derived from credit trading policy tools.

## 2.2. Literature review

### 2.2.1. Passenger car market competition

Faced with the actual competition in current automotive market, existing studies focused on four stages that market introduction, niche market penetration, mass-market penetration, and potential market dominance of new energy vehicles [26]. The first type of research concentrated on new energy vehicle introduction strategies, such as the competition between the first mover and followers in introducing alternative powertrain technologies [27], and the competition in portfolio decisions between two manufacturers [28,29]. Second, existing studies regarding niche market penetration stage mainly considered the role of subsidy on new energy vehicle promotion, which will be elaborated in the next subsection. Third, as opposed to researches on other stages, the research about mass-market penetration stage analyzed the vertical interaction behavior of various upstream and downstream participants in automotive supply chain [30–32]. They aimed to develop equilibrium strategies for maximizing industrial chain profit. Fourth, the stage of potential market dominance, where scholars focused on the duopoly competition game between manufacturers or supply chains that produce new energy vehicles and internal combustion engine vehicles, respectively [33–36]. The optimal strategies and profit variations of both parties under different competition and cooperation models were discussed.

Several scholars have studied HEEs that produce both internal combustion vehicle and new energy vehicle. For example, Chen *et al.* [37] separately considered three product selection strategies for an automaker in the context of differential subsidy or DCP, namely gasoline vehicles only, both gasoline vehicles and electric vehicles, and electric vehicles only. Ou *et al.* [38] explored a vehicle manufacturer's production or introduction strategy for conventional vehicles, battery electric vehicles, plug-in hybrid electric vehicles and fuel cell vehicles, and analyzed the impact of differential DCP on HEE's profit and consumer choices. Lou *et al.* [39] built a model consisting of a group of conventional manufacturers that produce a large number of internal combustion engine vehicles and a small number of new energy vehicles to analyze their impact by DCP. Further, Yu *et al.* [40] investigated the three-way game among manufacturer, retailer and consumer, and the manufacturer produces both electric vehicles and internal combustion engine vehicles. In contrast, Cheng and Fan [33] analyzed which of unified production, NEV priority production, and fuel vehicle production is the best strategy for manufacturers' best cooperation strategy under the background of fuel automaker and new energy automaker co-funding HEE. Based on this, Shao *et al.* [41] constructed a duopoly model of electric-fuel-manufacturer supply chain and fuel manufacturer supply chain to explore the impact of subsidy on the sales of different energy types of vehicles.

### 2.2.2. The impact of the subsidy policy

Studies on the subsidy policy cover single policy efficiency and policy mix utility. The former focused on the impact of subsidy phase-out on automakers' behavioral strategies [42]. Relative studies present different views. Some studies indicated the subsidy is beneficial to promote vehicle electrification [43], and the market significantly responds to this price signal that incentivizes new energy vehicles consumption [42,44]. Some studies proposed the subsidy has little impact on new energy vehicle proliferation [45], and the subsidy withdrawal is beneficial to new energy vehicle development [24]. In addition, other studies presented the subsidy has non-unidirectional effects. For example, Yu *et al.* [46] argued that ex-ante subsidy and ex-post subsidy affect the profits of new energy vehicle enterprises in a positive U-shape and an inverted U-shape, respectively.

Combined utility studies focused on the impact of policy combinations of subsidy and tax relief [47,48], fuel vehicle license plate restriction [49] on new energy vehicle diffusion. As subsidy declines, its replacement policy that DCP has received some attention with its complementary effect [50]. Yu *et al.* [40] pointed out that when CAFC credit reaches equilibrium, subsidy decline will reduce demand for both internal combustion engine vehicles and new energy vehicles. Li *et al.* [36] proposed that subsidy reduction has a positive impact on both new energy vehicle supply chains and internal combustion engine vehicle supply chains, and can partially offset DCP's negative effect on the former as a temporary profit supplement, but cannot significantly change the overall profit structure of the latter. The view that the tightening DCP trend puts firms under greater policy

pressure is also endorsed by Wu *et al.* [51], who further indicated that the subsidy may be adjusted again to ensure corporate sustainable development.

### 2.2.3. *The impact of DCP*

DCP derives from policies such as fuel efficiency and greenhouse gas emission standards. Most passenger car enterprises around the world are operating under related policies aiming at energy efficiency and emission reduction, and there is a tightening trend in such policies. For example, the ZEV mandate, first issued in the United States [52], was similarly implemented in Canada; the corporate average fuel economy standards and credit system set by Korea [53]; the mandatory emission reduction standards specified by EU in Regulation No. 333 [54].

Regarding Chinese DCP, scholars have extensively analyzed the impact of DCP on different types of vehicles [33], explored consumer behavior and industry profit under four scenarios that no-rules, CAFC-credit only, NE-credit only, and DCP [38]. Studies regarding the impact of DCP on the change in the market share of ICE-PC and NE-PC have not yet reached a consistent conclusion. One view is that the market share of internal combustion engine vehicles reduces while that of new energy vehicles increases with DCP implementation [55], which benefits the profit of new energy vehicle supply chain while reducing that of internal combustion engine vehicle supply chain [36]. Contrary, another opinion is that DCP is less efficient [56–58]. Wu *et al.* [51] pointed out that DCP cannot guarantee enterprises produce more low fuel consumption vehicles and new energy vehicles. Furthermore, Lou *et al.* [39] supposed DCP may reduce the fuel economy of internal combustion engine vehicles or promote automakers to increase the production of vehicles with high fuel consumption. The reason for the contradictory conclusion is the decomposability of DCP, consisting of CAFC credit rule and NE credit rule.

### 2.2.4. *Approaches to competition study*

Most pre-existing studies used game theory, system dynamics model, agent-based modeling, and econometric model to study competition issues. The latter three approaches mainly consider endogenous feedback structures that represent stakeholders as rule-following agents in a virtual environment [27]. To focus on the firm's competitive strategies aimed at profit maximization, we use game theory approach. As a systematic mathematical tool, game-theoretic approach can be used for iterative and interactive quantitative analysis [55, 56]. Game theory approach has been widely applied in the cooperative or competitive game between different players such as government and automakers [57], manufacturers and retailers [58], technology and performance [59, 60].

The shortcomings of existing studies are presented as follows. First, although previous researches explored competition among distinct passenger car types and automakers, ignoring the real players in the market are HEE and NEE. Moreover, most studies neglected the only common objective of mainstream policies is passenger car, extending the study to car, causing the results to deviate from the actual situation. Third, the policy context of the simultaneous implementation of the subsidy and DCP in this paper is closely related to several studies, but the game subject is different. Li *et al.* [36] constructed a game model consisting of a conventional vehicle supply chain and a new energy vehicle supply chain. Chen *et al.* [37] explored the product selection strategy of an HEE. Yu *et al.* [40] investigated the three-way game problem among manufacturer, retailer and consumer. Differently, the subject of this paper spotlights between HEE, which has just introduced NEV technologies and products, and NEE, which is a new entrant to passenger car market. Given that DCP can be divided into two dimensions, CAFC credit regulation and NE credit regulation, previous researches mainly used assigning CAFC credits and NE credits (multipliers) for each passenger car production when exploring specific policy effects. This paper further breaks down the policy tools at CAFC credit regulation level and NE credit regulation level. Meanwhile, since only a systematic development of multifaceted policies can advance the sustainable transition process [61], policy makers generally consider the separate and combined effects of policy tools when arranging and coordinating policies [62, 63]. Therefore, in contrast to the established studies that only consider the separate effects of credit policy tools, this paper further analyzes the combined effect of credit policy tools at same credit regulation level.

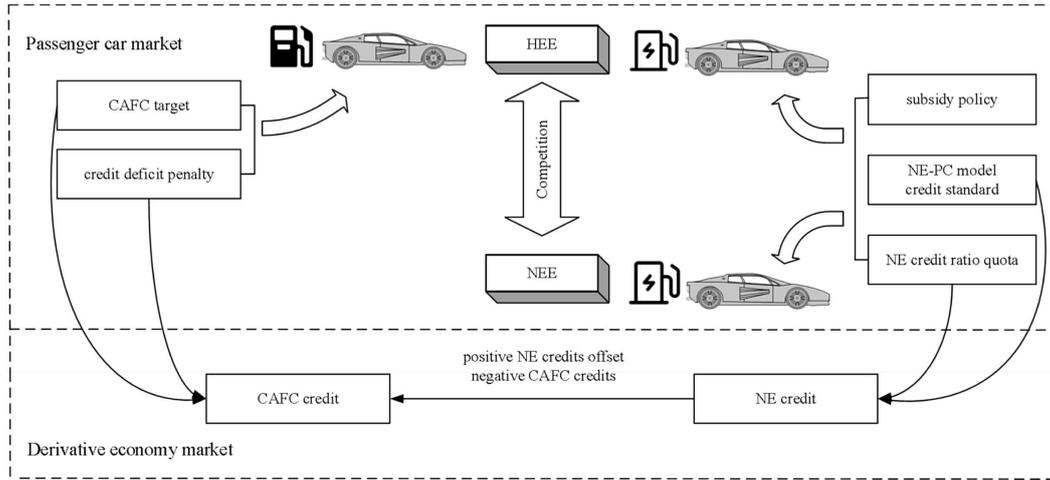


FIGURE 2. Concept of the competition model.

The contributions of this paper focus on three main aspects. (1) A duopoly competition model is constructed to study the pricing strategy and profit structure of the new entrant NEE that produces only NE-PCs, and to discuss competitive threat to the existing enterprise by a new entrant with highly cleaner technology. (2) In the context of NE-PC subsidy phase-out and credit trading policy tools tightening, this paper explores the product layout of HEE producing ICE-PCs and NE-PCs, enriching the theory of product selection and supply diversification. (3) By discussing the interactive effects of credit trading policy tools on same governance level, this paper provides strategic suggestions for enterprises undergoing new energy transition and new entrants receiving policy support.

This study constructs a duopoly game competition model consisting of an HEE that produces both ICE-PCs and NE-PCs, and a NEE that only makes NE-PCs<sup>3</sup>. The general concept of core policies' impact on HEE and NEE competition is shown in Figure 2. The policy tools on CAFC credit regulatory level include CAFC target and credit deficit penalty, mainly acting on HEE producing ICE-PCs. The subsidy policy and the policy tools on NE credit rule level include NE-PC model credit standard and NE credit ratio quota, mainly act on HEE and NEE producing NE-PCs. HEE and NEE not only compete in the passenger car sales market, but also have an economic transaction in the market derived from credit trading policies, where HEE purchases positive NE credits from NEE.

### 3. MODEL DESCRIPTION

For conveniently tracking parameters, Table 1 presents the notations involved in the model.

In the main competitive market that passenger car market, NEE can be considered a new entry enterprise, while HEE is an existing enterprise. This study constructs a duopoly competitive game model consisting of an HEE and a NEE interacting in passenger car market and credit trading market. HEE sells ICE-PC and NE-PC at an average price of  $P_{HEE}$ , and NEE sells NE-PC with  $P_{NEE}$ . The production cost of a NE-PC produced by both automakers is  $c_n$ , and that of an ICE-PC produced by HEE is  $c_m$ . Since the scale effect of ICE-PC is higher than NE-PC,  $c_n > c_m$ . The total amount of subsidy for each NE-PC sold is set to  $s$ .

<sup>3</sup>Given that this research focuses on the competition among passenger car manufacture enterprises, the role of retail enterprises in passenger car market are not discussed for the time being. Therefore, the passenger car manufacture enterprises are set to sell passenger cars directly to consumers.

TABLE 1. Notations.

Notations	Descriptions	Notations	Descriptions
$P_{HEE}$	Average price of HEE	$P_{NEE}$	Average price of NEE
$Q_{HEE-m}$	ICE-PC production of HEE	$Q_{NEE-n}$	NE-PC production of NEE
$Q_{HEE-n}$	NE-PC production of HEE	$s$	Subsidy for a NE-PC
$c_m$	Production cost of an ICE-PC	$c_n$	Production cost of a NE-PC
$a_m$	Market size upper boundary of ICE-PCs	$a_n$	Market size upper boundary of NE-PCs
$\mu_m$	Price sensitivity coefficient of ICE-PCs	$\mu_n$	Price sensitivity coefficient of NE-PCs
$p_d$	Penalty per negative credit	$p_i$	Unit positive NE credit price
$l$	CAFC quota for the accounting year	$\bar{Y}$	NE-PC model credit
$\bar{k}$	CAFC target per passenger car	$\beta$	NE credit ratio quota
$\bar{r}_{HEE}$	CAFC actual value of HEE		

### 3.1. Production function

According to the assumptions of Bertrand monopoly model, production follows demand function [64]. HEE and NEE compete on price in the market, and they simultaneously make their pricing strategies for profit maximization. Referring to the inverse demand function set by Singh and Vivesf [65] and Lusand and Muriel [66], we construct the demand functions for ICE-PC and NE-PC produced by HEE are shown as equations (1) and (2), respectively, and that for NE-PC produced by NEE is presented as equation (3).

$$Q_{HEE-m} = a_m - \mu_m P_{HEE}, \tag{1}$$

$$Q_{HEE-n} = a_n - \mu_n P_{HEE}, \tag{2}$$

$$Q_{NEE-n} = a_n - \mu_n P_{NEE}. \tag{3}$$

In the above expressions,  $a_m$  and  $a_n$  indicate the market size upper boundary of ICE-PCs and NE-PCs, respectively. Goldsmith *et al.* [67] indicated consumers reaction with variation to price changes of different products, namely price sensitivity.  $\mu_m$  and  $\mu_n$  represent the price sensitivity coefficients of the two types of passenger cars' consumer separately ( $\mu_m > \mu_n > 0$ ).

There is a significant degree of customer loyalty in consumers' passenger car purchasing behavior. According to the results of CAACS survey conducted by China Automotive Repair Industry Association, 78% of consumers tend to choose the same brand when purchasing a car for the second time [68]. Brand loyalty is a central determinant of consumer automotive purchase behavior. It has been well established that unless there is a significant difference in basic attributes, potential buyers will barely wave in their customer loyalty to preferred car brands [69]. There is no significant difference in the basic attributes of NE-PC produced by HEE and NEE, so consumers who trust HEE brands such as Toyota and BMW will still choose HEE brands when purchasing NE-PC. Meanwhile, consumers who are more likely to recognize the NE-PC technology of NEE brands such as Tesla will purchase NEE's passenger car. Therefore, this paper does not consider the product substitution effect between HEE and NEE.

### 3.2. Dual-credit calculation and the transaction of positive NE credit

As a mixture of CAFC credit rule and NE credit procedure, DCP specifies the methods to cover negative CAFC credits: (i) using the positive CAFC credits self-carried forward or transferred from associated enterprises. (ii) using the positive NE credits self-generated or purchased. Meanwhile, the methods to cover negative NE credits include: (i) purchasing positive NE credits. (ii) using the positive NE credits self-carried forward or

TABLE 2. The formula of DCP.

	HEE		NEE
	ICE-PC	NE-PC	NE-PC
(1) CAFC credit	$(\bar{l}k - \bar{r}_{\text{HEE}})(Q_{\text{HEE}-m} + Q_{\text{HEE}-n})$		$\bar{l}kQ_{\text{NEE}-n}$
(2) NE credit	$-\beta Q_{\text{HEE}-m}$	$\bar{Y}Q_{\text{HEE}-n}$	$\bar{Y}Q_{\text{NEE}-n}$

generated in subsequent years. The passenger car enterprises, whose positive NE credits generated are not enough to offset negative CAFC credits, have to purchase positive NE credits at price  $p_i$ . According to DCP, the enterprises holding negative credits will lose approval for selling passenger cars. Given that quantifying credit deficit penalty is a better way to analyze the operation behaviors of enterprises, this paper quantifies the penalty  $p_d$  ( $p_d > p_i > 0$ ).

### 3.2.1. Relevant parameters background

As a primary means of avoiding credit deficit penalty, enterprises holding negative credits purchase positive NE credits from enterprises with redundant tradable positive NE credits at price  $p_i$ . Policy makers have not yet imposed constraints on credit trading market such as upper and lower price limits, so credit price will fluctuate with changes in market supply and demand, *e.g.* the difference in average trading price between 2020 [20] and 2021 [21] is 884 CNY per credit. Considering that NE credit has become an important liquid product among passenger car enterprises, the dynamic impact of changes in credit price on passenger car enterprises' competitive strategies will be analyzed later.

According to DCP, the penalty for enterprises failing to meet the standards is to revoke the sales qualification of relevant products. For the penalty is too severe, all vehicle enterprises will avoid non-compliance. Therefore, this paper assumes that  $p_d$  is for the profit of high fuel consumption models sold less in compliance.

### 3.2.2. The calculation of CAFC credit

The formula for CAFC credit calculation is mathematically expressed as  $(\bar{l}k - \bar{r}_o) \times Q$ . In this expression,  $l$  indicates CAFC quota for the accounting year,  $\bar{k}$  represents unit CAFC target, and the multiplier  $\bar{l}k$  presents CAFC up-to-standard value.  $\bar{r}_o$  reflects enterprise  $o$ 's CAFC actual value. Separately, the average CAFC actual value of HEE is set as  $\bar{r}_{\text{HEE}}$ . Without internal combustion engine R&D base, the types of NE-PCs produced by NEE do not include plug-in hybrid passenger cars. Based on the *Fuel Consumption Evaluation Methods and Targets for Passenger Cars*, the CAFC actual value of NEE  $\bar{r}_{\text{NEE}}$  is 0. For simplicity, the corresponding multiplier for the car model is normalized to 1.  $Q$  represents the total number of passenger cars produced or imported by enterprises in the accounting year. When CAFC actual value is less than CAFC up-to-standard value, CAFC credit is positive, and the opposite presents a deficit. The formulas for calculating the CAFC credit of HEE and NEE are shown in the row (1) of Table 2.

### 3.2.3. The calculation of NE credit

The formula for calculating NE credit is  $\bar{Y}Q_n - \beta Q_m$ , where  $\bar{Y}$  represents average NE-PC model credit for response NE-PC model credit standard;  $Q_n$  reflects the production or imports of NE-PC; and the term  $\bar{Y}Q_n$  indicates NE actual credit. The parameter  $\beta$  refers to NE credit ratio quota;  $Q_m$  is the production or imports of ICE-PC; and the term  $\beta Q_m$  stands for NE credit target. When NE actual credit is greater than NE credit target, NE credit is positive, and the reverse is true. The formulas for calculating the NE credit of HEE and NEE are shown in the row (2) of Table 2.

### 3.2.4. The transaction of positive NE credit

As can be seen from the accounting formulas, both the CAFC credit and NE credit of NEE under the current policy setting are positive. According to the dual credit statistics for the single year 2020, the value of

tradable positive NE credits is +3.27 million, which is not enough to cover the shortfall of −7.45 million CAFC credits [19]. As a result, passenger car enterprises stand in a scenario where the demand for positive NE credit exceeds supply. HEE holds negative credits, and has to purchase all of NEE's redundant positive NE credits with expenses of  $-p_i \bar{Y} Q_{NEE-n}$ . In addition, HEE still has negative credits that have not been offset after transaction, thus should pay penalty  $p_d [\bar{Y} (Q_{HEE-n} + Q_{NEE-n}) - \beta Q_{HEE-m} + (\bar{l}k - \bar{r}_{HEE}) (Q_{HEE-m} + Q_{HEE-n})]^4$ .

### 3.3. Profit function

The profit functions of HEE and NEE are expressed as follows.

$$\begin{aligned} \underset{P_{HEE}}{\text{maximize}} \pi_{HEE} &= (P_{HEE} - c_m) Q_{HEE-m} + (P_{HEE} - c_n + s) Q_{HEE-n} - p_i \bar{Y} Q_{NEE-n} \\ &\quad + p_d [\bar{Y} (Q_{HEE-n} + Q_{NEE-n}) - \beta Q_{HEE-m} + (\bar{l}k - \bar{r}_{HEE}) (Q_{HEE-m} + Q_{HEE-n})], \end{aligned} \quad (4)$$

$$\underset{P_{NEE}}{\text{maximize}} \pi_{NEE} = (P_{NEE} - c_n + s) Q_{NEE-n} + p_i \bar{Y} Q_{NEE-n}. \quad (5)$$

### 3.4. Equilibriums conditions

It can be deduced that the profit function of HEE and NEE with respect to price is convex. We calculate the first-order conditions of HEE and NEE price in equations (4) and (5) respectively and set them equal to zero. The following two equations are obtained.

$$\begin{aligned} \frac{\partial \pi_{HEE}}{\partial P_{HEE}} &= a_m + a_n + (c_m - P_{HEE}) \mu_m - P_{HEE} \mu_m - P_{HEE} \mu_n \\ &\quad - (s - c_n + P_{HEE}) \mu_n + p_d [\beta \mu_m - \bar{Y} \mu_n - (\bar{l}k - \bar{r}_{HEE}) (\mu_m + \mu_n)] = 0, \end{aligned} \quad (6)$$

$$\frac{\partial \pi_{NEE}}{\partial P_{NEE}} = a_n - (s - c_n + 2P_{NEE} + \bar{Y} p_i) \mu_n = 0. \quad (7)$$

Simultaneous equations (6) and (7) can gain the unique optimal price of HEE and NEE, as shown below.

$$P_{HEE}^* = \frac{1}{2(\mu_m + \mu_n)} \{ a_m + a_n + [c_m + (\beta + \bar{r}_{HEE} - \bar{l}k) p_d] \mu_m + [c_n - s + (\bar{r}_{HEE} - \bar{l}k - \bar{Y}) p_d] \mu_n \}, \quad (8)$$

$$P_{NEE}^* = \frac{1}{2\mu_n} [a_n + (c_n - s - \bar{Y} p_i) \mu_n]. \quad (9)$$

Substituting equations (8) and (9) into corresponding Eqs. (1)–(3), the optimal productions of HEE and NEE can be obtained.

$$\begin{aligned} Q_{HEE-m}^* &= \frac{1}{2(\mu_m + \mu_n)} \{ a_m (\mu_m + 2\mu_n) \\ &\quad - \mu_m \{ a_n + [c_m + (\beta + \bar{r}_{HEE} - \bar{l}k) p_d] \mu_m + [c_n - s + (\bar{r}_{HEE} - \bar{l}k - \bar{Y}) p_d] \mu_n \} \}, \end{aligned} \quad (10)$$

$$\begin{aligned} Q_{HEE-n}^* &= \frac{1}{2(\mu_m + \mu_n)} \{ a_n (2\mu_m + \mu_n) \\ &\quad - \mu_n \{ a_n + [c_m + (\beta + \bar{r}_{HEE} - \bar{l}k) p_d] \mu_m + [c_n - s + (\bar{r}_{HEE} - \bar{l}k - \bar{Y}) p_d] \mu_n \} \}, \end{aligned} \quad (11)$$

$$Q_{NEE-n}^* = \frac{1}{2} [a_n + (s - c_n + \bar{Y} p_i) \mu_n]. \quad (12)$$

<sup>4</sup>Since the trading price of positive NE credit is lower than credit deficit penalty, HEE first purchases positive NE credit to offset negative credits, and then pays penalty for the uncompensated portion.

Further, substituting equations (8)–(12) into equations (4) and (5) gets the maximum equilibrium profit of HEE and NEE.

$$\begin{aligned} \pi_{\text{HEE}}^* = & \frac{1}{4(\mu_m + \mu_n)^2} \left\{ -2\bar{Y}p_i(\mu_m + \mu_n)^2 [a_n + (s - c_n + \bar{Y}p_i)\mu_n] + [2 - G\mu_m - 2c_m(\mu_m + \mu_n) - \phi\mu_n] \right. \\ & [2\mu_n + \mu_m(G\mu_m + \phi\mu_n)] + [2 + 2(s - c_n)(\mu_m + \mu_n) - G\mu_m - \phi\mu_n][2\mu_m + \mu_n(G\mu_m + \phi\mu_n)] \\ & - 2p_d(\mu_m + \mu_n) \left\{ (\bar{r}_{\text{HEE}} - \bar{l}\bar{k})(\mu_m + \mu_n)(2 + G\mu_m + \phi\mu_n) + \beta[\mu_m + 2\mu_n - \mu_m(1 - G\mu_m \right. \\ & \left. - \phi\mu_n)] + \bar{Y}[-3(\mu_m + \mu_n) - (\mu_m + \mu_n)(s - c_n + \bar{Y}p_i)\mu_n + \mu_n(2 - G\mu_m - \phi\mu_n)] \right\} \left. \right\}. \end{aligned} \tag{13}$$

**Note:** Let  $G = -c_m - \beta p_d + \bar{l}\bar{k}p_d - \bar{r}_{\text{HEE}}p_d$ ,  $\phi = s - c_n + \bar{l}\bar{k}p_d + \bar{Y}p_d - \bar{r}_{\text{HEE}}p_d$ .

$$\pi_{\text{NEE}}^* = \frac{[a_n + (s - c_n + \bar{Y}p_i)\mu_n]^2}{4\mu_n}. \tag{14}$$

#### 4. OPTIMAL EQUILIBRIUM STRATEGY ANALYSIS AND SENSITIVITY ANALYSIS

##### 4.1. Static analysis

In the context of keeping all parameters constant, this paper presents a static comparative analysis of the product selection strategy of HEE, the equilibrium strategies of HEE and NEE.

###### 4.1.1. HEE’s ICE-PC and NE-PC production layout analysis

**Proposition 1.** *As for HEE, when the difference between CAFC up-to-standard value and actual value satisfy the relational expression  $\bar{l}\bar{k} - \bar{r}_{\text{HEE}} = \frac{2+(c_m+\beta p_d)\mu_m+(c_n-s-\bar{Y}p_d)\mu_n}{p_d(\mu_m+\mu_n)}$ , its ICE-PC production will equal NE-PC production. HEE will produce more NE-PC when the difference is below the threshold, and more ICE-PC production when the difference exceeds the threshold.*

As shown in Proposition 1, the product layout of HEE is related to the difference between CAFC up-to-standard value and actual value. Compared to the main business that passenger car sales, HEE is more concerned with the sum of its economic benefits in actual operation. Specifically, the high fuel consumption caused by producing ICE-PC will raise negative CAFC credits and the expenditure for purchasing positive NE credits. The positive NE credits earned from producing NE-PC can offset negative CAFC credits.

When the difference between CAFC up-to-standard value and actual value is higher than the threshold, the negative effect from negative CAFC credit is relatively small. HEE will continue to take ICE-PC, which has higher market power, as its main product. In this scenario, because of the information asymmetry between the government and enterprises, the below-limit policy setting will result in an effect contrary to the policy meaning. As the difference between CAFC up-to-standard value and actual value is below the threshold, the high negative CAFC credits to be offset will force HEE to make NE-PC as the main product.

###### 4.1.2. NE-PC production strategy analysis of HEE and NEE

**Proposition 2.** *When satisfying the following condition that  $\mu_m - \mu_n - (s + c_m - c_n + \beta p_d)\mu_m\mu_n - p_d\mu_n(\bar{l}\bar{k} - \bar{r}_{\text{HEE}})(\mu_m - \mu_n) + \bar{Y}\mu_n(p_d\mu_n - p_i\mu_n - p_i\mu_m) = 0$ , the NE-PC production of HEE and NEE are equal.*

According to Proposition 2, we can conclude that three exogenous factors can affect the gap between NE-PC production of HEE and NEE, namely, NE credit ratio quota  $\beta$ , the difference between CAFC up-to-standard value and actual value  $\bar{l}\bar{k} - \bar{r}_{\text{HEE}}$ , NE-PC model credit standard  $\bar{Y}$ . First, the NE-PC production of HEE is higher when NE credit ratio quota is set below the limit  $\beta^* = \frac{\mu_m - (s + c_m - c_n + \bar{l}\bar{k}p_d - \bar{r}_{\text{HEE}}p_d + \bar{Y}p_i)\mu_m\mu_n + \mu_n[-1 + \bar{l}\bar{k}p_d\mu_n - \bar{r}_{\text{HEE}}p_d\mu_n + \bar{Y}(p_d - p_i)\mu_n]}{p_d\mu_m\mu_n}$ , while the NE-PC production of NEE is higher when the policy tool is set above  $\beta^*$ . This is a phenomenon worth exploring, which implies that as NE credit ratio quota increases, there is a two-stage impact on the market share of enterprises in NE-PC market.

The first stage is that the increase in NE credit ratio quota promotes the NE-PC production and R&D of HEE. According to the theory of constrained production capacity, HEE does not have the technology and capital to meet the entire NE-PC market demand, and thus will not compete aggressively with NEE. Therefore, the portion of HEE’s NE-PC production that exceeds NEE is small. Considering the calculation formula of NE credit, in the second stage when NE credit ratio quota is above the threshold, the reduction in NE credit increases HEE’s expenditure to compensate for negative CAFCCredits. Further, because of the reduction in fixed costs available for production, HEE’s NE-PC production is easily overtaken by NEE.

Similarly, the NE-PC production of HEE is higher than NEE when the difference between CAFCCredits up-to-standard value and actual value produced by HEE  $l\bar{k} - \bar{r}_{HEE}$  is above the negative threshold  $\frac{\mu_n[-1+\bar{Y}(p_d-p_i)\mu_n]-\mu_m[-1+(s+c_m-c_n+\beta p_d+\bar{Y}p_i)\mu_n]}{p_d(\mu_m-\mu_n)\mu_n}$ , while that of NEE is higher when the difference is below the negative threshold. Policy adjustments influence the strategies of market players. The setting of CAFCCredits target can affect the enterprise distribution of NE-PC market by changing the production strategy of HEE.

Differently, the NE-PC production of HEE is higher when the average NE-PC model credit is above the threshold  $\bar{Y}^* = \frac{\mu_m-(s+c_m-c_n+\beta p_d+l\bar{k}p_d-\bar{r}_{HEE}p_d)\mu_m\mu_n-\mu_n(1-l\bar{k}p_d\mu_n+\bar{r}_{HEE}p_d\mu_n)}{-\mu_n[p_d\mu_n-p_i(\mu_m+\mu_n)]}$ , and that of NEE is higher when average NE-PC model credit is below  $\bar{Y}^*$ . This means that HEE insights that NE-PC production can generate significantly more positive NE credits when NE-PC model credit exceeds the threshold. Profit growth drives HEE to produce more NE-PCs than NEE. As NE-PC model credit standard tightens below the threshold, the negative impact of this policy tool on HEE will not be sufficient to change HEE product layout, and HEE will not compete fiercely with NEE in NE-PC market.

4.1.3. Consumer price sensitivity analysis

This section analyzes the effect of differential consumer price sensitivity on the equilibrium competitive strategies of HEE and NEE.

**Proposition 3.** *In the context of consumers’ differential price preferences for ICE-PC, the differences between HEE’s ICE-PC and NE-PC production strategies are as follows.*

Conditions		$\mu_m$	Comparison between $Q_{HEE-m}^*$ and $Q_{HEE-n}^*$	
$G \geq 0$	$\sigma\mu_n \geq 2$	$(0, +\infty)$	$Q_{HEE-m}^* < Q_{HEE-n}^*$	
	$\sigma\mu_n < 2$	$\sqrt{G\mu_n} - \sqrt{(4-2\sigma\mu_n)} \geq 0$	$(0, +\infty)$	$Q_{HEE-m}^* \leq Q_{HEE-n}^*$
		$\sqrt{G\mu_n} - \sqrt{(4-2\sigma\mu_n)} < 0$	$(0, \mu_{m2}]$	$Q_{HEE-m}^* \geq Q_{HEE-n}^*$
			$(\mu_{m2}, +\infty)$	$Q_{HEE-m}^* < Q_{HEE-n}^*$
$G < 0$	$\sigma\mu_n \geq 2$	$(0, \mu_{m1}]$	$Q_{HEE-m}^* \leq Q_{HEE-n}^*$	
		$(\mu_{m1}, +\infty)$	$Q_{HEE-m}^* > Q_{HEE-n}^*$	
		$(0, +\infty)$	$Q_{HEE-m}^* > Q_{HEE-n}^*$	
	$\sigma\mu_n < 2$	$(0, +\infty)$	$Q_{HEE-m}^* > Q_{HEE-n}^*$	

**Note:**  $\sigma = s + c_m - c_n + \beta p_d + \bar{Y} p_d$ ,  $\mu_{m1} = \frac{G\mu_n + \sqrt{2G\mu_n(2-\sigma\mu_n)}}{-G}$ ,  $\mu_{m2} = \frac{G\mu_n - \sqrt{2G\mu_n(2-\sigma\mu_n)}}{-G}$ .

The results of Proposition 3 suggest there is a track record of driving HEE’s green transition through changes in consumer sensitivity to ICE-PC prices. There are various effects of consumers’ ICE-PC price preferences on HEE’s product selection strategy in different contexts. Combined with the premise assumptions of Bertrand

monopoly model, production follows demand function [64]. It can be inferred that consumers' ICE-PC price preference is an important factor driving whether they purchase ICE-PC or NE-PC, but the effect varies from different contexts. Specifically, in the context of low ICE-PC production cost, high NE-PC and low  $\bar{l}k - \bar{r}_{HEE}$ , the NE-PC demand for HEE will be larger than ICE-PC when the consumer price sensitivity to ICE-PC rises above  $\mu_{m2}$ . In the context of low NE-PC production cost and low  $\bar{l}k - \bar{r}_{HEE}$ , the NE-PC demand for HEE will be larger than that of ICE-PC when the consumer price sensitivity of ICE-PC is lower than  $\mu_{m1}$ .

**Proposition 4.** *In the context of differential consumer price preferences for NE-PC, the differences in NE-PC production strategies between HEE and NEE are as follows:*

		Conditions	$\mu_n$	Comparison between $Q_{HEE-n}$ and $Q_{NEE-n}$
$\omega p_d - \bar{Y} p_i \geq 0$	$\sigma \mu_n \geq -2$	$\sqrt{(\omega p_d - \bar{Y} p_i) \mu_m} - \sqrt{2 + \sigma \mu_m} \geq 0$	$(0, +\infty)$	$Q_{HEE-n}^* \geq Q_{NEE-n}^*$
		$\sqrt{(\omega p_d - \bar{Y} p_i) \mu_m} - \sqrt{2 + \sigma \mu_m} < 0$	$(0, \mu_{n2}]$	$Q_{HEE-n}^* \leq Q_{NEE-n}^*$
			$(\mu_{n2}, +\infty)$	$Q_{HEE-n}^* > Q_{NEE-n}^*$
	$\sigma \mu_n < -2$		$(0, +\infty)$	$Q_{HEE-n}^* > Q_{NEE-n}^*$
$\omega p_d - \bar{Y} p_i < 0$	$\sigma \mu_n \geq -2$			$Q_{HEE-n}^* < Q_{NEE-n}^*$
	$\sigma \mu_n < -2$	$-\sqrt{-(\omega p_d - \bar{Y} p_i) \mu_m} + \sqrt{-2 - \sigma \mu_m} \geq 0$	$(0, \mu_{n1}]$	$Q_{HEE-n}^* \geq Q_{NEE-n}^*$
				$(\mu_{n1}, +\infty)$
		$-\sqrt{-(\omega p_d - \bar{Y} p_i) \mu_m} + \sqrt{-2 - \sigma \mu_m} < 0$	$(0, +\infty)$	$Q_{HEE-n}^* < Q_{NEE-n}^*$

**Note:**  $\omega = \bar{l}k + \bar{Y} - \bar{r}_{HEE}$ ,  $\mu_{n1} = \frac{-\omega p_d \mu_m - \bar{Y} p_i \mu_m + \sqrt{(\omega p_d - \bar{Y} p_i) \mu_m (2 + \sigma \mu_m)}}{\omega p_d - \bar{Y} p_i}$ ,  $\mu_{n2} = \frac{-\omega p_d \mu_m - \bar{Y} p_i \mu_m + \sqrt{(\omega p_d - \bar{Y} p_i) \mu_m (2 + \sigma \mu_m)}}{\omega p_d - \bar{Y} p_i}$ .

The results of Proposition 4 suggest that, in the context of differential consumer price preferences for NE-PC, NE-PC production of NEE is not constant higher than that of HEE. With the adjustment of the policy tools at NE credit regulation level, the NE-PC production of HEE is likely to exceed that of NEE. As production is driven by demand, it can be deduced that consumer price sensitivity to NE-PC is a key factor in whether they purchase NE-PCs made by HEE or NEE, but consumer price sensitivity to NE-PC results in different consumption choices in different contexts. Concretely, in the scenario of low  $\bar{l}k - \bar{r}_{HEE}$ , low ICE-PC cost and high NE-PC cost, the NE-PC demand for HEE will exceed that of NEE when the consumer price sensitivity to NE-PC drops below the threshold  $\mu_{n1}$ . Conversely, in the context of high  $s$ , high  $\beta$  and low NE-PC cost, the NE-PC demand for HEE exceeds that of NEE only when the consumer price sensitivity to NE-PC is higher than  $\mu_{n2}$ .

### 4.2. Dynamic analysis

The equilibrium strategies for HEE and NEE are subject to dynamic changes influenced by multiple factors over time. This section considers the effects of five different types of factors: cost fluctuation, credit price change, subsidy phase-out, tightening of the policy tools at CAFC credit regulation level, and tightening of the policy tools at NE credit regulation level.

#### 4.2.1. The impact of cost fluctuation

Since different passenger car enterprises produce and sell ICE-PCs with varying fuel consumption and NE-PCs with diverse energy-efficient technologies, this section analyzes the impact of differential production cost and cost fluctuations on the equilibrium strategies and revenues of HEE and NEE.

**Proposition 5.** *The higher the cost of ICE-PC and NE-PC, the higher the price of HEE's and NEE's products.*

Proposition 5 reveals that in a competitive passenger car market, passenger car enterprises with high manufacture costs typically sell their products at high prices. This proposition matches the real-world scenario. The cost of vehicles varies across fuel-efficient technologies. Compared to battery electric vehicles, hydrogen fuel cell vehicles have immature technology processes and therefore sell at a higher price. For example, the officially launched Changan Deep Blue SL03 is available in three power options: extended-range version, battery electric version and hydrogen energy version, with prices of 168,900 yuan, 215,900 yuan and 699,900 yuan respectively [70]. Therefore, differential fuel consumption systems and energy-saving technologies will drive passenger car enterprises to develop different pricing strategies. The more mature the fuel consumption system process and energy-saving technologies are, the lower the manufacture cost of passenger cars are, and hence the lower the enterprises' pricing. Meanwhile, the cost of competing products does not have impact on the price strategy of enterprises. In other words, the impact of cost fluctuations of ICE-PC on NEE's price strategy is minimal and can be ignored.

**Corollary 1.** *The impact of passenger car costs on the pricing strategies of HEE and NEE is as follows.*

- (a) *The price of HEE's products decreases more with the reduced cost of ICE-PC than that of NE-PC.*
- (b) *Compared to the price of HEE's products, the price of NEE's products decreases more with NE-PC's cost.*

Corollary 1 presents that the cost scale effect has a profound impact on the price strategy of enterprises. Specifically, regarding to HEE, the activities associated with ICE-PC production and sales are more mature than NE-PC, so the cost reduction of ICE-PC will bring more space for price reduction. Meanwhile, compared with HEE, NEE's NE-PC production and sales activities are more sophisticated, and thus the cost reduction of NE-PC will bring more space for NEE to reduce price.

**Proposition 6.** *With the decrease in ICE-PC cost and NE-PC cost, both HEE's ICE-PC and NE-PC production increase; NEE's NE-PC production increases only with the decrease in NE-PC cost.*

Similar to the changes in product prices, enterprises' passenger car production fluctuates only with the cost of the self-manufactured products, and the fluctuation trend is consistent with the classical theory. For HEE, ICE-PC production increases with decreasing HEE's ICE-PC cost, and NE-PC production increases with decreasing NE-PC costs for both HEE and NEE. It is worth noting that HEE's ICE-PC production also increases with the decrease in NE-PC cost, because NE-PC is also one of HEE's important product line, and the decrease in its cost will drive the increase in the production capacity of HEE's total products. In addition, NEE's NE-PC production does not change with the decrease in ICE-PC cost, which means that a decrease in the cost of competitive products will not affect enterprises' production strategy.

**Corollary 2.** *The impact of passenger car costs on the passenger car production of enterprises is as follows.*

- (a) *HEE's ICE-PC production and NE-PC production decreases more with the increased cost of ICE-PC than that of NE-PC.*
- (b) *Compared to NEE, the NE-PC production of HEE decreases less with increasing NE-PC cost.*

Similar to how prices fluctuate with costs, HEE has a higher cost advantage in ICE-PC, so lower cost for this category will drive production of all HEE's products up more. Compared to NE-PC cost, HEE's ICE-PC production increases more with decreasing ICE-PC cost; HEE's NE-PC production increases more with decreasing ICE-PC cost. NEE has a higher NE-PC manufacture process and innovative technology than HEE. Consequently, as NE-PC cost decreases, NEE will add more NE-PC production than HEE.

#### 4.2.2. The impact of changes in credit price

The credit price will change to a certain extent as the supply-demand ratio of NE credit fluctuates. It is predictable that credit price is higher when the supply of NE credit is less than demand compared to the case when supply is above demand.

**Proposition 7.** *Only the equilibrium price and production of NEE vary with credit price. As credit price increases, NEE will cut price and increase NE-PC production.*

As the supply-demand ratio of positive NE credit decreases and thus credit price increases, NEE will cut price and increase production. Being a key source of revenue for NEE, the increase in credit price generates more additional revenue for NEE. NEE is able to adopt a price reduction strategy to capture more NE-PC market share while maintaining its existing revenue. Moreover, the current demand of positive NE credit in Chinese passenger car market exceeds supply, and there is no unsalable positive NE credit. The revenue increment from higher credit price provides NEE the capital needed to increase capacity, and thus NEE will likewise increase production.

The equalization strategy of HEE does not change with credit price movement. The main reason is that HEE's NE-PC development is not yet sufficient. As a result, HEE is in a long-term credit deficit and well above the positive NE credits available from NEE. The penalty for credit deficit is significantly higher than the market price of trading credit, specifically, the Chinese government has implemented the suspension of product sales licenses for enterprises with credit deficit. Accordingly, the profit loss from penalty is much higher than the expenditure on positive NE credit purchase. Therefore, the increase in credit price due to the decrease in the supply-demand ratio of positive NE credits has a minimal impact on HEE's strategy. To achieve credit trading policies' purpose that promoting HEE green transformation, policy makers should set a minimum limit of credit price.

**Lemma 1.** *The price competition between HEE and NEE follows a threshold rule.*

$$\text{Let } p_i^* = \frac{a_n \mu_m + \mu_n [-a_m - (s + c_m - c_n + \beta p_d - l k p_d + \bar{r}_{\text{HEE}} p_d) \mu_m + (l k + \bar{Y} - \bar{r}_{\text{HEE}}) p_d \mu_n]}{\bar{Y} \mu_n (\mu_m + \mu_n)}.$$

When  $p_i > p_i^*$ ,  $P_{\text{HEE}}^* > P_{\text{NEE}}^*$ ; otherwise, when  $p_i < p_i^*$ ,  $P_{\text{HEE}}^* < P_{\text{NEE}}^*$ .

Tirole [10] indicated that a set of products always interacts with other goods at economic level. There is a certain degree of economic linkage between passenger car and positive NE credit. Lemma 1 illustrates that the price difference between HEE and NEE can be reflected by the rational equation between positive NE credit price and credit deficit penalty. When the credit price reaches the threshold  $p_i^*$ , the average price of HEE and NEE are equal, after it raises above the threshold, HEE will adopt a higher price strategy than NEE. The reason is that credit premium causes an increase in the marginal cost of HEE and a decrease in that of NEE. Consequently, HEE will raise price while NEE will cut price.

Conversely, if positive NE credit price decreases below the threshold  $p_i^*$ , HEE's price will be lower than NEE's price. When NEE cannot gain substantially from the profit loss of HEE, HEE may make predatory prices relying on its scale advantage, thereby attracting more consumers, scaring off potential competitors trying to enter the market, or even driving rivals out of the market.

Price competition is the main means for HEE and NEE to compete in passenger car market in short term. Lower price will generate higher demand. There is a negative externality between HEE and NEE in that a price reduction by either party will result in a decrease in the rival's market share. When developing pricing strategies, both parties should not only focus on the short-term gains after a price cut and losses in a long-term price war, but also consider whether production capacity can meet the sustained growth in demand due to price reduction. As for HEE, the weak NE-PC technology and ICE-PC operating expense do not allow it has the production capacity to meet whole demand, thus fierce price competition is not necessary. Yet for NEE, the current scenario is the best time to take advantage of a price war to occupy market share, where it can gain additional revenue from positive NE credit sales, the subsidy has not yet been fully withdrawn, and HEE needs to balance both ICE-PC and NE-PC. For example, Tesla launched the Model Y version with standard range

in July 2021, whose performance is similar to the Model Y version with long-range, yet the 71,900 CNY price reduction strategy directly drove excessive orders and paralyzed the official website. Therefore, NEE prefers to cut price leading to market pressure on HEE. It is worth noting that when credit price is below the threshold, the average price of NEE will be higher than that of HEE. The reason is that NEE's competitive advantage in credit market is weakened because of the lower demand for positive NE credit from rival HEE, or the lower market price due to the relaxed regulation of related policy tools. Accordingly, when NEE cannot continuously accumulate capital to increase production capacity, the excessive demand due to low NE-PC price will become a liability. Differently, as the comprehensive revenue improves on account of the expense reduction on positive NE credit purchase, HEE can achieve market share expansion through appropriate price cut.

#### 4.2.3. *The impact of subsidy phase-out*

**Proposition 8.** *With NE-PC subsidy receding, both HEE and NEE will raise price, with NEE's price rising faster. In contrast, the production of both will decline, with the rate of decline ranked from highest to lowest being NEE's NE-PC, HEE's ICE-PC, and HEE's NE-PC.*

As a policy tool to promote product sales, NE-PC subsidy works directly on consumers. As the subsidy gradually recedes, the cost of purchasing a NE-PC increases and consumer surplus decreases. Counter-intuitively, both HEE and NEE will raise price. The main reason is the low sensitivity of potential NE-PC consumers to price change and the low impact of subsidy on NE-PC sales [45]. In fact, the subsidy that the government can afford is not sufficient to bridge the price gap between NE-PC and ICE-PC, and cannot improve effectively the relative competitiveness of NE-PC [71]. For example, the NE-PC namely Song Pro EV Noble model and the ICE-PC namely Song Pro luxury car model are both produced by BYD and similarly equipped, but the expenditure for purchasing the NE-PC after subsidy is still higher than the ICE-PC by 100 thousand CNY. In other words, the subsidy phase-out causes a small decline in sales, and NE-PC manufacturers attempt to compensate for the profit loss by raising price. For example, Tesla domestic Model 3 is priced at 250,900 CNY until 2022, and after a 30% subsidy withdrawal in 2022, the price has been raised by 4752 CNY to 255,652 CNY. Similarly, the price of domestic Model Y has been increased from 276,000 CNY to 280,752 CNY [72]. Tesla's domestic sales in the fourth quarter of 2021 were 178,097 units, while those in the first quarter of 2022 were 182,174 units [73]. It is clear that the subsidy withdrawal drives up passenger car prices and have little impact on sales. This view is supported by data from the overall passenger car industry. 2020 full-year NE-PC sales were 2.279 million units, up 153.3% year-on-year [74]; in 2021, the subsidy is withdrawn by 20%, but NE-PC sales are 3.494 million units, up 169.1% year-on-year [12]; in 2022, the subsidy is withdrawn by 30%, but NE-PC retail sales have reached 4.432 million units in January–October, up 107.5% year-on-year [75]. It can be seen that subsidy withdrawal has little impact on NE-PC sales. Furthermore, according to Proposition 8, given that HEE's product layout is spread over two modules, ICE-PC and NE-PC, its price strategy is rising at a slower pace than that of NEE.

According to product selection theory, the two products produced by HEE are to some extent substitutable for each other. When the withdrawal of NE-PC subsidy leads to them becoming less attractive to potential consumers, HEE's monopoly power over ICE-PC will promote its demand function to move upward. However, Proposition 8 states that HEE's ICE-PC production also shows a decreasing trend as the subsidy recedes. The main reason is that NE-PC has become a key development plan for HEE because of policy pressure and market trends [11]. Within the overall policy-driven background, HEE's NE-PC production and sales should be maintained rather than reduced, if not show an increasing trend. However, the withdrawal of the subsidy acting on consumer purchase stage will lead to an increase in the purchase price of NE-PCs, which will reduce the purchase willingness of some consumers. The main way to maintain NE-PC price is to reduce production costs through R&D to improve production technology. When NE-PC receives lower subsidies, enterprises will have to reallocate their existing resources. To ensure the R&D and production resources required for NE-PC remain unchanged or even grow continuously, enterprises divert resources from another mainstream product, ICE-PC, to NE-PC. This has led to a decline in ICE-PC capacity and a drop in production. Accompanied by a 30% reduction in NE-PC subsidy, ICE-PC retail sales in China from January to October in 2022 were 12.28 million

units, down 13% year-on-year [75]. Moreover, it is worth noting that NEE's yield declines at a higher rate than HEE's yield during the subsidy rollback process. This indicates that the subsidy has greater impact on NEE product sales than on HEE. The practical reason for this conclusion is that for NEE, the NE-PC is its only passenger car product and the subsidy withdrawal will certainly cause potential consumer loss. In addition to NE-PC, HEE also produces the rival ICE-PC, and it is highly likely that consumers who are discouraged from purchasing NE-PC due to the subsidy withdrawal will switch to ICE-PC. Furthermore, the subsidy withdrawal will cause HEE's ICE-PC production and sales to decline more than its NE-PC production and sales. This indicates that the policy signal of subsidy withdrawal has conveyed a clear market development direction to HEE, which is to change from a policy of encouraging NE-PC development to a policy of mandating NE-PC development. In view of the subsidy phase-out and the reduction in R&D and production resources for NE-PC, HEE will allocate more R&D and production resources from ICE-PC to NE-PC for the long-term sustainable development.

**Proposition 9.** *The impact of the subsidy phase-out on the profits of HEE and NEE is as follows:*

- (a) *HEE's profit declines due to subsidy phase-out.*
- (b) *There is a threshold value  $s^* = c_n - \bar{Y}p_i - \frac{a_n}{\mu_n}$  for the effect of the subsidy on NEE profit. When  $s^* > 0$ , NEE profit first decreases and then increases with a decreasing subsidy; when  $s^* \leq 0$ , NEE profit only decreases with falling subsidy.*

In passenger car market, ICE-PC can be considered a complement to NE-PC. The subsidy acts directly on the sale segment of NE-PC. The short-term subsidy phase-out reduces the price advantage and market demand of NE-PC, and thus resulting in profit loss. However, a long-term subsidy rollback will highlight NEE's technology cost advantage, enabling NEE to make more profit as HEE reduces production due to the declining subsidy. The trade-off between these two opposing effects suggests the existence of a subsidy threshold  $s^*$ , which is the boundary value at which the subsidy has a contradictory effect on NEE profit. The threshold value depends on four variables, NEE profit only shows a downward trend with the subsidy retreat when the threshold is below 0, and will show a two-stage trend of falling and then rising with subsidy phase-out when the threshold is above 0.

#### 4.2.4. The impact of CAFC target and credit deficit penalty

Given that both CAFC target  $\bar{k}$  and credit deficit penalty  $p_d$  are oriented toward HEE producing ICE-PCs, to fully consider their separate roles and the existence of interactions, this paper discusses the impact of both on enterprises' competitive strategies.

**Lemma 2.**  *$p_d$  has a decisive impact on HEE pricing strategy, and the tightening of  $\bar{k}$  will exacerbate this impact.*

- (a) *The impact on HEE's pricing strategy is influenced by various factors, such as credit policy tools, HEE fuel consumption performance, and consumer price sensitivity. In detail, when satisfied  $\bar{k} < \frac{(\bar{Y} - \bar{r}_{HEE})\mu_n - (\beta + \bar{r}_{HEE})\mu_m}{l(\mu_m + \mu_n)}$ , HEE raises price with the tightening of  $\bar{k}$ , and the converse is also true.*
- (b) *As the value of  $\bar{k}$  goes down, HEE will raise price.*
- (c) *The tightening of  $\bar{k}$  will further exacerbate the impact of  $p_d$  on HEE's pricing strategy.*

When the expression  $(\beta - \bar{l}\bar{k} + \bar{r}_{HEE})\mu_m - (\bar{l}\bar{k} + \bar{Y} - \bar{r}_{HEE})\mu_n > 0$ , HEE will raise price as  $p_d$  increases, and vice versa. As  $\bar{k}$  decreases, it becomes more difficult for HEE to meet the requirement. To achieve a lower  $\bar{k}$ , HEE may increase R&D input to reduce fuel consumption per ICE-PC or purchase positive NE credit to offset credit deficit resulting from the difference between  $\bar{k}$  and CAFC actual value. HEE thereby will raise price to cover the increased cost expense or credit purchase expense.

There is some interaction between the two policy tools designed to promote energy efficiency and emission reduction in ICE-PC for HEE's pricing strategy. The constraint enhancement of these two policy tools is increasing  $p_d$  and decreasing  $\bar{k}$ . Numerically, these two policy tools are strengthened in opposite ways. Therefore, if both  $p_d$  and  $\bar{k}$  are strengthened, it will have a synergistic amplifying effect on HEE's pricing strategy.

**Lemma 3.** *The increase of  $p_d$  and the tightening of  $\bar{k}$  not only have an independent effect on the production strategy of HEE, but the interaction of the two will show an opposite effect.*

- (a) *The impact of  $p_d$  on HEE’s production strategy is influenced by various factors, such as the credit policy tools, HEE fuel consumption performance, and consumer price sensitivity. Specifically, when  $\bar{k} < \frac{(\bar{Y}-\tau_{\text{HEE}})\mu_n-(\beta+\tau_{\text{HEE}})\mu_m}{l(\mu_m+\mu_n)}$ , HEE will reduce production with increasing  $p_d$ , and ICE-PC production will be reduced faster than NE-PC, and the converse is also true.*
- (b) *As the value of  $\bar{k}$  is adjusted downward, HEE will reduce production, and the decrease in ICE-PC production will be greater than NE-PC.*
- (c) *The tightening of  $\bar{k}$  will ease the HEE’s production reduction strategy due to the increase in  $p_d$ .*

Similar to the variation of the price strategy, when  $\bar{k} < \frac{(\bar{Y}-\tau_{\text{HEE}})\mu_n-(\beta+\tau_{\text{HEE}})\mu_m}{l(\mu_m+\mu_n)}$ , HEE will reduce production as  $p_d$  increases, and *vice versa*. As  $\bar{k}$  decreases, it becomes more difficult for HEE to reach the target. Combined with Lemma 1, HEE may generate more negative CAFC credits under a lower  $\bar{k}$  scenario. The way to avoid penalty include increasing R&D input to reduce negative credit generation and raising credit purchase expense to compensate for negative credits. The increase in other expenses will result in a reduction in regular production capacity, thus reducing product yields.

There is an interactive effect of two policy tools designed to promote energy efficiency and emission reductions on the production strategies of HEE. The simultaneous strength of  $p_d$  and  $\bar{k}$  have opposite effects on the production strategies of HEE. In detail, narrowing  $\bar{k}$  will mitigate the impact of increased  $p_d$  on HEE curtailment. A proper retrenchment of both policy tools in parallel can bring a respite to HEE’s production curtailment. However, when the two policy tools are tightened too strongly may cause detrimental impact. Although the achievement of R&D input cannot be realized in a short time, the net profit from HEE capacity reduction is much lower than that from ICE-PC sales accompanied by NE credit purchase or fine expense. Therefore, policy maker should slowly raise  $p_d$  and narrow  $\bar{k}$ , rather than tightening them at the same time.

4.2.5. *The impact of NE-PC model credit standard and NE credit ratio quota*

Since both NE-PC model credit  $\bar{Y}$  and NE credit ratio quota  $\beta$  are intended for passenger car enterprises producing NE-PCs, this paper discusses the impact of both on market competition simultaneously to fully consider their separate effects and whether there is an interaction between them.

**Lemma 4.** *The impact of the two credit policy tools at NE credit regulation level on enterprises’ pricing strategies is as follows:*

- (a) *With reducing  $\bar{Y}$ , both HEE and NEE will raise price.*
- (b) *An increase in  $\beta$  would only facilitate HEE raising prices.*

The reduction in  $\bar{Y}$  causes an increase in HEE’s credit deficit, which also raises the fixed cost that HEE uses to purchase positive NE credits or pay credit deficit penalty. Price increase is a common means of recovering fixed costs [76]. The amount of positive NE credits that NEE can use for trading also decreases with the downward adjustment of  $\bar{Y}$ . When  $\bar{Y}$  is reduced, the increase in HEE’s price is significantly higher than that of NEE. Moreover, the annual increment in  $\beta$  will lead to a slight increase in HEE’s pricing strategy. According to the NE credit accounting formula, the tightening of  $\bar{Y}$  leads to a decrease in NE credits held by HEE and NEE, which will further increase credit deficit for enterprises that produce only a small amount NE-PCs. Therefore, against the backdrop of tightening  $\bar{Y}$ , HEE should vigorously develop NE-PC technology and gradually increase NE-PC production.

**Lemma 5.** *The impact of the two credit policy tools accounting for NE credit on enterprises’ product layout is as follows:*

- (a) *Both HEE and NEE will reduce production as  $\bar{Y}$  tightens.*

- (b) *An increase in  $\beta$  only promotes HEE to reduce ICE-PC and NE-PC production, with the former decreasing more rapidly.*

During the tightening process of  $\bar{Y}$ , HEE's ICE-PC production decreases the fastest, followed by its NE-PC production. Meanwhile, an increase in  $\beta$  only promotes HEE to reduce production, and the decrease rate of ICE-PC is faster than that of NE-PC. The fundamental purpose of this type of policy tools is to promote the HEE transition to new energy direction. Therefore, such policy tools can precisely promote the transformation of enterprises, and their effect is consistent with the policy formulation objective.

**Proposition 10.** *The simultaneous tightening of  $\bar{Y}$  and the raising of  $\beta$  have a synergistic and amplifying dampening effect on HEE's revenue.*

The simultaneous tightening of the two policy tools designed to drive NE-PC development will have a synergistic amplifying effect on HEE's profit. The constraint enhancement of these two policy tools is decreasing  $\bar{Y}$  and increasing  $\beta$ . The former will cause less positive NE credits generated by producing a NE-PC and the latter will result in more negative NE credits generated by producing an ICE-PC. Proposition 10 presents that the simultaneous tightening of the two policy tools will cause a decrease in positive NE credits and an increase in negative NE credit generated by HEE, leading to an increase in positive NE credit expense or fines, resulting in an accelerated decrease in HEE's revenue.

## 5. NUMERICAL SIMULATIONS

### 5.1. Parameter setting

We perform numerical simulations using the real data from Chinese passenger car market. Based on the monthly production of passenger cars in 2020 [77], we set the market size as 1.5 million units. According to the *New Energy Vehicle Industry Development Plan*, the current sales volume of NE-PC needs to reach 20% of the new vehicle sales volume in 2025, thus setting the upper limit of ICE-PC  $a_m$  and NE-PC  $a_n$  at 1.2 and 0.3 million units, respectively.

Following the findings of Nie *et al.* [78], the consumer sensitivity to ICE-PC  $\mu_m$  and NE-PC  $\mu_n$  are 0.173 and 0.1, respectively.

Islam *et al.* [79] provided the cost of ICE-PC and NE-PC for large, medium, small, and SUV models. After averaging, we obtain the average manufacturing and R&D costs of ICE-PC  $c_m$  and NE-PC  $c_n$  are 0.1453 and 0.2169 million CNY, respectively.

According to a research report published by CATARC [80], the price of positive NE credit in 2020 ranges from 0.0026 to 0.0029 million CNY. The report also predicts that the price range will be between 0.0005 and 0.0014 million CNY in 2022. Therefore, we set positive NE credit price  $p_i$  to the median of 0.0005 and 0.0029 at 0.0017 million CNY.

The *latest New Energy Vehicle Subsidy Program* [81] specifies the subsidy range for NE-PC is between 0.0068 and 0.0225 million CNY. Given that the subsidy will be completely withdrawn, the minimum subsidy is set to 0 million CNY, so the subsidy range  $s$  is 0–0.0225 million CNY.

DCP [82] states NE credit ratio quota  $\beta$  from 2019 to 2023 are set from 10% to 18%; the annual CAFC ratio quota  $l$  from 2021 to 2024, 2025 and beyond are set from 123% to 100%, and we take the average value of 111.5% as the parameter assignment; the range of CAFC target  $\bar{k}$  is specified in the ranger of 4.015–6.771 L/100 km. The *revised DCP* [83] stipulates the range of NE-PC model credit  $\bar{Y}$  is between 0 and 9 credits per unit. The government announcement [19] shows that the average CAFC actual value  $\bar{r}_{\text{HEE}}$  is 5.61 L/100 km.

The quantification of credit deficit penalty is based on the government announcement that enterprises without satisfying dual-credit compliance will be required to suspend ICE-PC production [19]. First, the average passenger car price from January to December in 2020 is obtained from the GAIN Index report (reflecting end-user prices in the passenger car market) published by ISENGINE [84]. Second, the range of net profit per vehicle is estimated by subtracting the cost from the highest and lowest average price in passenger car market,

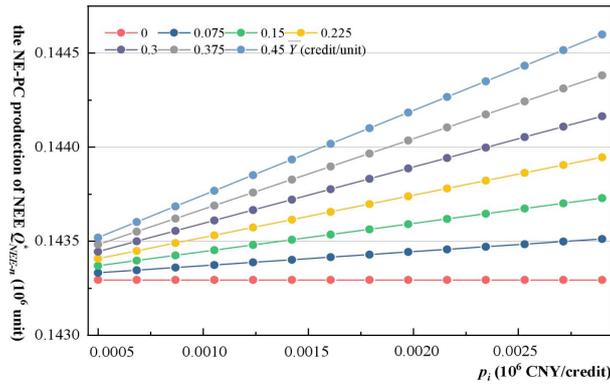


FIGURE 3. Effect of  $p_i$  on NEE’s NE-PC production.

respectively. Third, based on the negative CAFC credit and ICE-PC production of the non-compliant enterprises in 2020 published in the government announcement [19], the index of unit enterprise can be obtained by dividing the number of non-compliant enterprises respectively. Fourth, multiplying the maximum and minimum values of net profit per vehicle and the average ICE-PC production of enterprises, respectively, to obtain the ICE-PC profit range of HEE. Finally, the profit earned by ICE-PC was divided by the CAFC credit deficit to quantify the range of credit deficit penalty  $p_d$  is 0.0055–0.0168 million CNY.

### 5.2. The numerical analysis of credit price change

The effect of the change in credit price on the NE-PC production of NEE under different NE-PC model credit assignment backgrounds are simulated numerically, as shown in Figure 3. In the process of changing NE-PC model credit standard, the NE-PC production of NEE consistently increases with the increase of credit price. According to the market supply and demand theory, when the supply-demand ratio of positive NE credit decreases, the credit price will increase. As credit price increases, the credit sale revenue of NEE increases, NEE thereby can cut price and improve capacity. Overall, NEE’s NE-PC production decreases in response to credit price movements as NE-PC model standard gradually tightens. Specifically, for NEE, the tightening of NE-PC model credit standard will result in fewer positive NE credits to sell and thus no additional revenue to increase capacity.

### 5.3. The numerical analysis of subsidy phase-out

The effect of subsidy phase-out of the production of HEE and NEE are simulated numerically, as shown in Figure 4. Comparing the slopes, it can be seen that the ranking of passenger car enterprises affected by subsidy withdrawal are NE-PC production of NEE, ICE-PC production of HEE, NE-PC production of HEE. The reason why NEE is more significantly affected by the subsidy rollback is that, compare to HEE, which has operated in passenger car market for many years, new entrant NEE is still in the stage of expanding its brand effect and technology development. For example, Azera’s high-quality service, Xiaopeng’s cost performance advantage, and Tesla’s technology advantage all invariably raise manufacturing costs. Subsidy is an excellent channel to avoid the impact of higher manufacturing costs on sales through raising consumer purchase price. Therefore, the production of NEE is more significantly impacted by subsidy withdrawal than NEE. For HEE, in the context of mandatory regulatory policies such as DCP requiring NE-PC development, HEE can only transfer the resources originally belonging to ICE-PC to NE-PC by losing the subsidy’s boost to NE-PC. Therefore, compared to NE-PC production, the impact of subsidy withdrawal on HEE’s ICE-PC production is more obvious.

Further, the numerical experimental results of NE-PC yields of HEE and NEE affected by subsidy retreat are placed in the same figure, as shown in Figure 5. The NE-PC production of HEE is significantly lower than that

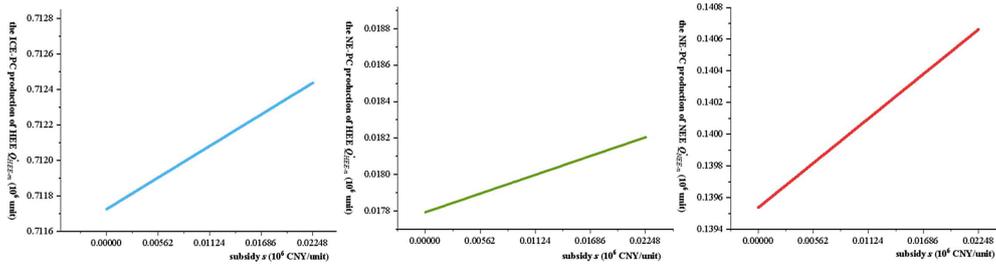


FIGURE 4. Effect of  $s$  on the production strategies of HEE and NEE.

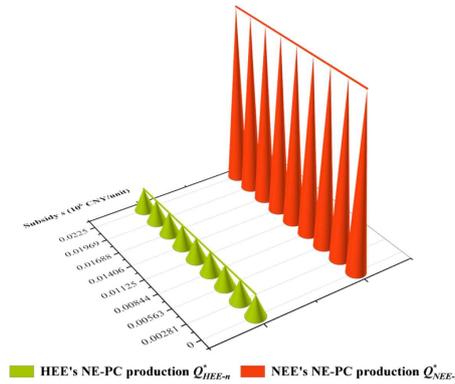


FIGURE 5. Effect of  $s$  on the NE-PC production of HEE and NEE.

of NEE with the policy tools set to the mean value. It is of concern that the impact of subsidy withdrawal on NE-PC production of HEE and NEE is minimal. The subsidy can be withdrawn as scheduled without causing significant negative vibrations to passenger car market.

#### 5.4. The numerical analysis of CAFC target and credit deficit penalty

The effects of CAFC target  $\bar{k}$  and credit deficit penalty  $p_d$  on the ICE-PC production and NE-PC production of HEE are simulated numerically, as shown in Figures 6 and 7. It is evident that the impact of  $\bar{k}$  and  $p_d$  on HEE's ICE-PC production is higher than that of NE-PC production, the major reason is the main purpose of these two policy tools is to promote energy saving and emission reduction in ICE-PC. Under the current numerical setting of the policy tools, both ICE-PC and NE-PC production of HEE decreases with  $\bar{k}$  tightening and increases with  $p_d$  raising. In addition, there is some interaction between the two credit policy tools at CAFC regulatory level on HEE's output decisions, but the impact is in the same direction for both outputs. When  $\bar{k}$  is set at a low level, the decrease in production of both HEE products with increasing  $p_d$  is less than the scenario where  $\bar{k}$  is set at a high level. Similarly, when the strength of  $p_d$  is low, the decline in production of both HEE products with tightening  $\bar{k}$  is less than in the scenario with a strong  $p_d$ .

The impact of  $\bar{k}$  and  $p_d$  on HEE profit is simulated numerically, as shown in Figure 8. Tightening trends in both  $\bar{k}$  and  $p_d$  will weaken HEE's competitiveness in the market, mainly due to lower demand resulting in a lower HEE margin [85]. ICE-PC production is decreasing faster than NE-PC production, which reflects the trend of shifting HEE's main product to NE-PC, and implies both the credit policy tools will drive HEE's green transition to some extent.

As for the interaction of the two policy tools, Figure 8 indicates that when  $\bar{k}$  is at a low level, HEE profit varies more with  $p_d$  enhancement than in the case where  $\bar{k}$  is at a high level. Contrary to usual thinking, when

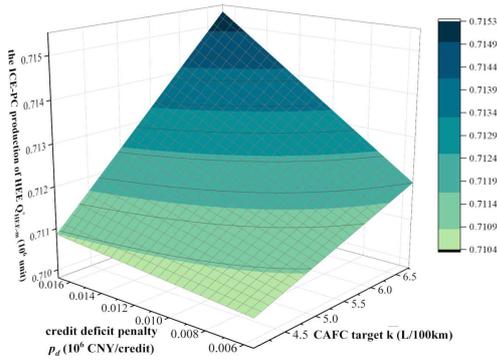


FIGURE 6. Effect of  $\bar{k}$  and  $p_d$  on HEE's ICE-PC production.

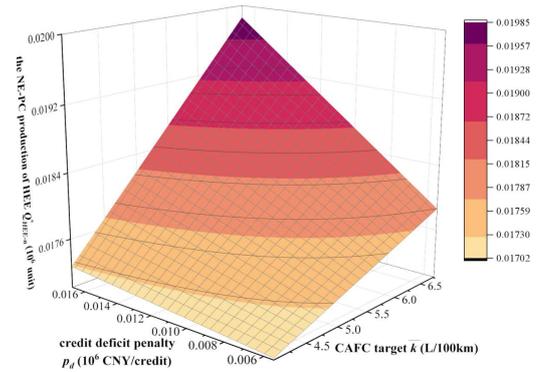


FIGURE 7. Effect of  $\bar{k}$  and  $p_d$  on HEE's NE-PC production.

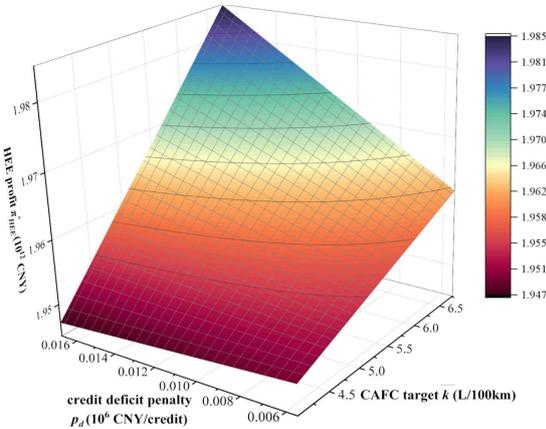


FIGURE 8. Effect of  $\bar{k}$  and  $p_d$  on HEE's profit.

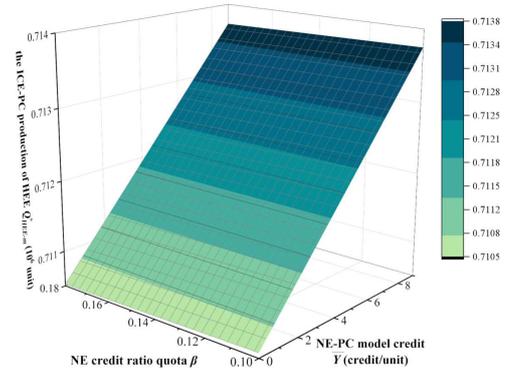


FIGURE 9. Effect of  $\bar{Y}$  and  $\beta$  on HEE's ICE-PC production.

$p_d$  is set at a high level, HEE's profit drops more as  $\bar{k}$  strengthens than in the case where  $p_d$  is low. This suggests that  $p_d$  still dominates the interaction between the two policy tools on HEE's profit, with  $\bar{k}$  playing a facilitating role.

### 5.5. The numerical analysis of NE-PC model credit standard and NE credit ratio quota

The effect of NE-PC model credit  $\bar{Y}$  and NE credit ratio quota  $\beta$  on the production of HEE and NEE are simulated numerically, as shown in Figures 9, 10 and 11. As  $\bar{Y}$  tightens, both HEE and NEE will reduce production, while the effect of  $\beta$  on HEE's production is minimal. The decline in both ICE-PC production and NE-PC production for both types of passenger car enterprises indicates that the policy tools should not be tightened quickly, otherwise it will adversely affect the production and sustainable development of passenger car market. HEE should shift its focus to the NE-PC product line expeditiously to avoid greater harm caused by the hardening of policy tools aimed at advancing NE-PC market share. NEE should invest more in NE-PC's R&D to improve its technical capability when the credit revenue is redundant, so as to avoid significant fluctuations in enterprise profits caused by tightening through reducing NE credits acquisition.

The effect of  $\bar{Y}$  and  $\beta$  on the profit of HEE and NEE is numerically simulated, as shown in Figures 12 and 13. The interaction between NE-PC model credit and NE credit ratio quota is not obvious, mainly because  $\beta$  increase

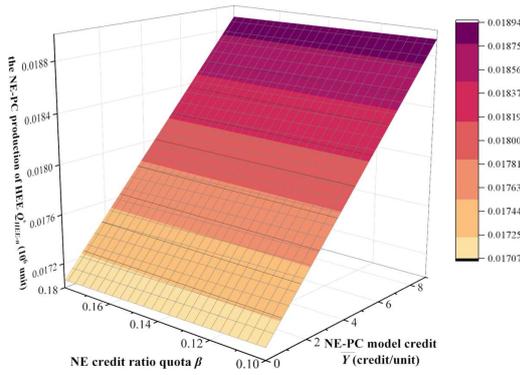


FIGURE 10. Effect of  $\bar{Y}$  and  $\beta$  on HEE's NE-PC production.

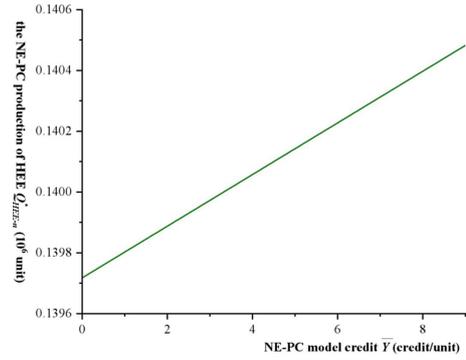


FIGURE 11. Effect of  $\bar{Y}$  on NEE's NE-PC production.

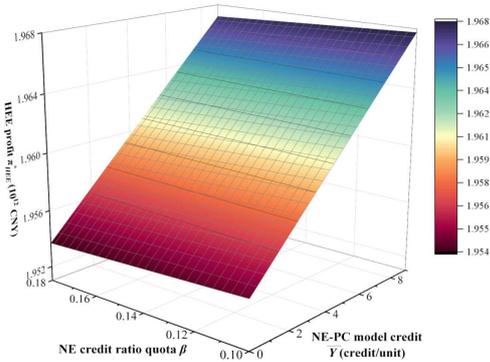


FIGURE 12. Effect of  $\bar{Y}$  and  $\beta$  on HEE's profit.

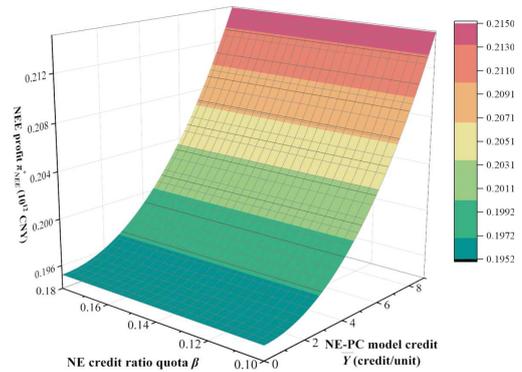


FIGURE 13. Effect of  $\bar{Y}$  and  $\beta$  on NEE's profit.

only minimally promotes HEE to raise price and reduce production. The two policy tools can regulate only the strategies of HEE producing ICE-PCs, without affecting NEE strategies. Combined with Lemmas 4 and 5, HEE will significantly reduce ICE-PC production to alleviate credit deficit as  $\bar{Y}$  decreases through reducing credit purchase expense. Under the background that both HEE's demand and NEE's supply for positive NE credit decrease, as the main income of NEE, the decline of credit transactions from HEE to NEE will cause a significant drop in HEE profit.

The analysis of the two policy tools calculating NE credit indicates, at present, they are notably beneficial to the profit of NEE rather than that of HEE. According to the dual-credit report, famous brands such as FAW Volkswagen, GAC Honda, and Beijing Benz all ranked at the bottom of NE credit standings, mainly because these HEEs still attach importance to the production and sales of ICE-PC rather than NE-PC in Chinese market [51]. Therefore, HEE will not compete fiercely with NEE in NE-PC market in short term. As the policy tools tighten, HEE's profit advantage formed through scale advantage and favorable policies will become increasingly evident. Overall HEE's strategies of raising price and reducing production, it is confirmed that credit purchase expense is the main factor causing the loss of HEE competitiveness.

## 6. CONCLUSIONS AND IMPLICATIONS

### 6.1. Conclusions

In passenger car market, NEE and HEE can be seen as new enterprise and existing enterprise, respectively. In credit trading market, NEE is on the supply side and HEE is on the demand side. In the context of subsidy phase-out and credit trading policy tools tightening, how HEE optimizes market layout and how NEE develops equilibrium operation strategies are common concerns of automakers and scholars. Using duopoly competition game method, this paper discusses the impact of subsidy and credit trading policy tools, which are the main tools of economic regulation, on the competition of passenger car enterprises, and the main conclusions are drawn.

- (1) The credit trading expenditure and income account for a large proportion in the profit structure of HEE and NEE. There is a great impact of the numerical relationship between positive NE credit price and credit deficit penalty on the pricing strategy of HEE and NEE. When credit price is above the threshold, HEE will make a higher average price than NEE, otherwise, the price of NEE's products will be higher.
- (2) A decline in the subsidy set for NE-PC will reduce HEE competitiveness while increasing NEE competitiveness. As the subsidy continues to be extended, the green transition process for HEE will also be prolonged. Conversely, the trend toward tightening NE-PC model credit standard and raising NE credit ratio quota will drive down the profits of both HEE and NEE simultaneously. The difference between CAFC up-to-standard value and actual value will affect HEE's product layout. When this difference increases to below the threshold, HEE will shift its main product from ICE-PC to NE-PC.
- (3) Compare to CAFC target and NE credit ratio quota, credit deficit penalty and NE-PC model credit standard have stronger effects on enterprise competition at their respective governance levels. There are interactions between policy tools at CAFC regulatory level. The reduction of CAFC target drives HEE strategies and profit to become more volatile with credit deficit penalty variations. As NE-PC model credit standard tightens, both HEE and NEE will reduce production, the former reducing production with credit deficit penalty and the latter reducing production with credit price. The increase in NE credit ratio quota only propels HEE to raise price and reduce production.

### 6.2. Implications

Based on the conclusions of this study, we offer the following three insights for passenger car enterprises in the context of competition.

- (1) HEE should reduce ICE-PC production more sharply, and increase R&D to achieve the cost scale advantage of NE-PC more quickly. For NEE, the current market environment where the supply of positive NE credit is less than demand is an essential time to accumulate capital and capture NE-PC market share. Therefore, NEE should consider a more radical competitive strategy to increase rigid production capacity by approaches such as improving production efficiency, and gaining market share by means like cutting price.
- (2) The threshold node of subsidy phase-out is critical to NEE. NEE can make an aggressive price strategy to occupy market and gain customer loyalty before the subsidy drops to the threshold. NEE should also plan ahead for the medium and long-term strategy when the policy tools at NE credit regulation level are tightened, and should consider accelerating technology research and development to form technical barriers, technology lock, or even participate in the development of technical standards. HEE should increase its investment in engine fuel reduction or NE-PC technology, rather than increasing its production capacity and engaging in a short-term price war. In addition, HEE should also develop a product layout strategy for each phase in the process of gradually widening the difference between CAFC up-to-standard value and actual value, with the perception that short-term gains brought by ICE-PC are not conducive to long-term development.

- (3) When credit deficit penalty is lower than the corresponding threshold, HEE can properly compete with NEE on price. As credit deficit penalty raises to above the threshold, the reduction of CAFC target will cause HEE to lose its price advantage. At this point, HEE should produce enough NE-PCs or continue to purchase positive NE credit to avoid credit deficit penalty. Conversely, NEE should grasp each optimization node of the policy tools at CAFC credit regulation level, and implement phase strategies of expanding market share.

Due to space constraints, this paper only discusses enterprise-level competition in Chinese passenger car market. In reality, the upgrading and transformation of passenger car industry also involve the decision-making issues of other players, such as consumers' sensitivity to changes in policy tools. Therefore, we will further explore the multiparty game between enterprises and consumers in passenger car market.

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