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Chapter: Economic Dimensions of Sustainable Development

OPERATING STRATEGY UNDER SUBSIDY PHASE-OUT: JOINT PRICING AND PRODUCT LINE CONFIGURATION FOR ELECTRIC AND TRADITIONAL VEHICLE MODELS

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Annotation. Against the backdrop of carbon peak and carbon neutrality targets and the transformation of the automotive industry, China's new energy vehicle (NEV) subsidies have entered a phase of gradual reduction, leading to a substantial decrease in external incentives. Traditional automobile manufacturers qualified to produce NEVs must make production decisions between NEVs and conventional internal combustion engine vehicles based on operational performance. These decisions directly influence transformation efficiency and profit stability. However, existing research conducted under the subsidy phase-out scenario has insufficient focus on actionable threshold-type production decision rules and standardized analytical frameworks for production operations and supply chain configurations. To investigate how consumer premiums for NEV performance influence the optimal mixed production and joint pricing through the demand structure after subsidy withdrawal, drawing on structural contingency theory, a joint decision-making model is constructed with profit maximization as the objective. Static equilibrium derivation and comparative static analysis were used to characterize the response of optimal decisions to key parameters, and threshold identification was performed to define critical conditions for strategy switching. Results indicate that (1) the level of consumer premium is positively correlated with the proportion of NEV production. When the premium is below a certain threshold, manufacturers produce only conventional vehicles; when it exceeds another threshold, only NEVs are produced. (2) An increase in consumer premium leads to a decrease in the total number of car buyers, which eventually stabilizes at about half of the original scale. (3) The manufacturer's optimal profit has a U-shaped relationship with consumer premium, that is, profits decrease initially and then increase. The conclusions provide a methodological reference and policy insights for automobile manufacturers to balance profit stability and technological diffusion in the green transition.

Keywords: operation management, production and pricing, mixed production, new energy vehicles, subsidy phase-out.

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Introduction

The electrification of transportation is one of the key paths for deep decarbonization in China, and it can help the country achieve its carbon peak and carbon neutrality goals. The Chinese automotive market ranks among the largest globally, and the transportation sector is one of the key areas of carbon emissions in China, accounting for about 10% of the country's total carbon emissions. In 2024, China's carbon emissions reached 1.26 billion tons, with transportation emissions amounting to around 1 billion tons, second only to emissions from electricity and industries. According to the Ministry of Public Security of China, in 2024, the number of vehicles in China reached 353 million. If the stock of vehicles continues to grow, China's transportation carbon emissions will reach 1.2–1.7 billion tons per year by 2030 (He *et al*., 2005; Yan and Crookes, 2009; Huo and Wang, 2012). Against this backdrop, new energy vehicles (NEVs), including hybrid vehicles, battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles, have become the core of industrial transformation and the dual-carbon pathway because of their high energy efficiency and low emissions (Yuan *et al.*, 2015).

At the industrial practice level, subsidy policies played an important role at the early stages of the NEV industry, but with the optimization of policy combinations under the dual-carbon strategy and enhanced market orientation, subsidies have gradually been phased out, and their withdrawal has become a set direction. Some traditional car manufacturers launched parallel NEV product lines on the basis of their production of traditional internal combustion engine vehicles (CEVs) during the early stages of NEV development (e.g., BYD Tang/Song/Qin, SAIC Roewe RX5/eRX5, i5/ei5, and BMW's parallel product lines), demonstrating the feasibility of implementing a hybrid production strategy during the subsidy period. Moreover, some qualified manufacturers have long ceased production or have been producing low-quality NEVs just to obtain subsidies. After subsidy withdrawal, traditional car manufacturers with NEV qualifications must optimize their hybrid production and pricing strategies for NEVs and CEVs under increased market competition and dual-carbon constraints to maximize profits and align with the low-carbon transformation.

From the perspective of operation management, the market equilibrium of NEV–CEV products is endogenously shaped by policy and consumer utility. On the demand side, government subsidies and the relative utility of the two vehicle technologies determine the willingness to pay premiums and selection probabilities. Individual heterogeneity (such as income, education level, environmental preferences, price acceptability, and performance perception) adjusts price–attribute elasticity, with characteristics, performance, and subsidies substantially increasing marginal utility and conversion probabilities. However, in certain contexts, the marginal effects of usage costs and charging infrastructure coverage are limited (Zhang, 2014; Erdem and Şimşek, 2010; Lin *et al.*, 2018). On the supply side, subsidies alter unit economics and marginal contributions, restructuring a firm's product mix and capacity configuration. This alteration induces endogenous choices in the parallel layout and structural share between NEVs and CEVs, with dynamic adjustments to the production schedule and model combination in response to subsidy intensity, market acceptance, and cost constraints, to balance demand uncertainty and market cannibalization (Shao *et al.*, 2017; Zheng *et al.*, 2018). Overall, subsidies act simultaneously on demand utility and supply decisions, jointly determining the penetration paths and competitive dynamics of NEVs and CEVs.

In response to existing studies that regarded subsidies as exogenous and long-term and generally exogenized consumers' willingness to pay a premium for NEVs (Hong *et al.*, 2012; Luo *et al.*, 2014; Shao *et al.*, 2017; Zheng *et al.*, 2018; Zhang, 2014; Cheng *et al.*, 2018), this work places the research context in the post-subsidy phase, emphasizing the endogenous premium determined by consumer preferences for NEV performance, which drives joint production–pricing linkages in firms. Theoretically, this study adopts structural contingency theory (SCT) as the overarching research framework. This theory emphasizes that no universal optimal strategy exists in organizational management; instead, organizational performance depends on the alignment with the external environment and strategy. When environmental parameters exceed critical thresholds, optimal configurations undergo threshold-based shifts (Donaldson, 2001; Drazin and Van de Ven, 1985; Venkatraman, 1989; Venkatraman and Prescott, 1990). Therefore, this study investigates how the evolution of demand structures in the post-subsidy context changes firms' product line and pricing choices between NEVs and CEVs and derives identifiable strategic thresholds and boundary conditions. Unlike existing work that focused on optimal pricing or mixed production in the presence of subsidies, this study identifies how premiums, via the demand structure, affect firms' product mix and market equilibrium after subsidy exit and characterizes testable strategy thresholds and boundary conditions. This study focuses on the following research questions. (1) How do endogenous changes in consumer premiums in the post-subsidy scenario reshape the optimal production ratio and corresponding equilibrium prices between NEVs and CEVs? (2) Which premium thresholds trigger the strategic switch from mixed production (NEV+CEV) to exclusive NEV production? (3) What is the functional form of manufacturer profit with respect to the premium? Is it U-shaped? What cost–demand factors jointly determine its turning point?

This study provides the following main contributions. (1) In the post-subsidy scenario, this study regards consumer premium for NEV performance as an endogenous demand parameter, linking it with firms' product mix, pricing, and production ratios. The study constructs a joint decision-making model with profit maximization as the goal and mechanistically explains how premiums influence optimal prices, market shares, and production structure, thereby correcting the existing literature's exogenous treatment of subsidies and premiums. (2) This study builds a unified equilibrium framework with consumer premium as the central state variable. In a relaxed demand–cost setting, the framework characterizes the existence, uniqueness, and switching boundaries of NEV and CEV product mix choices via threshold structures, offering global comparative static results and shape constraints. This framework provides operational constraints for structural estimation and empirical testing, with potential for broad application to general demand elasticity and cost structures. (3) Through numerical simulation, this study quantifies the sensitivity of key cost parameters (such as battery/material costs, production line transformation costs, and price transmission coefficients) to threshold positions and profit function forms and identifies feasible ranges for post-subsidy production line conversion, mixed production, and price transmission. It provides actionable production scheduling and product line configuration rules as well as testable parameters for policy calibration.

The structure of the remaining sections is as follows. Section 2 presents a review of relevant literature. Section 3 shows the construction of the automotive manufacturer equilibrium decision model and the derivation of optimal production strategies. Section 4 introduces the numerical simulations conducted to validate the model. Section 5 discusses the implications of the model results, provides testable predictions, and defines applicable boundaries. Section 6 concludes the study and presents future research directions.

1. Literature Review

In the policy phase where subsidies are replaced by tax incentives, automobile manufacturers need to re-optimize their product mix and pricing strategies between NEVs and traditional internal CEVs. At the end of 2022, the central government's purchase subsidies were officially phased out, and from 2024 to 2027, purchase tax exemptions will continue, reshaping the relative price signals and expectations on the demand and supply sides (Li and Zhang, 2023). Meanwhile, global industry assessments indicate that even though subsidies have been phased out, China's market penetration rate for NEVs remains high, and the marginal effect of charging network expansion on adoption continues to rise (Alsharif, 2025). Structural econometric research on the Chinese market has also identified a forward shift in purchase timing and dynamic demand responses caused by the gradual reduction and termination of subsidies (Hu *et al.*, 2025). On the basis of these institutional and market realities, this chapter discusses two main themes: (1) the endogenous nature of the demand system and the willingness to pay for attributes and (2) product mix and threshold structures in multiproduct decisions.

1.1 Endogenization of the Demand System and Willingness to Pay for Attributes

Existing research generally began with a structured demand framework, regarded the observable attributes of NEVs (such as range, charging convenience, reliability, and usage costs) as the core components of utility, and characterized demand intensity through consumers' willingness to pay for these attributes. In terms of identification, this approach aligns with the Berry–Levinsohn–Pakes system, using market share inversion and exogenous instrumental variables to address price endogeneity and unobserved product characteristics, thereby identifying the relationships among price, share, and premiums from market-level data (Berry *et al.*, 1995; Berry and Haile., 2014).

In the context of China, empirical evidence exhibits strong consistency with this framework. Discrete choice experiment-based studies have found that the marginal contributions of range and charging accessibility are robust, and substantial heterogeneity exists across dimensions, such as income, environmental preferences, and usage scenarios (Han and Sun, 2024). Structural estimation based on a random coefficient logit model further characterizes price-share elasticity and substitution patterns, providing an identifiable empirical framework for the endogenous coupling of attribute premiums, prices, and demand shares (Xiong *et al.*, 2023). Cross-national comparisons also indicate that Chinese consumers have a strong preference for medium- to long-range BEVs/PHEVs (Helveston *et al.*, 2015). Corresponding meta-analyses have quantitatively assessed the tradeoff between range and fast-charging accessibility and revealed that when the range reaches a certain threshold, the marginal effect of network accessibility on choice probability increases (Rosales-Tristancho *et al.*, 2024).

At the mechanism level, demand formation is also influenced by network externalities and policy timing. A bilateral promotional relationship exists between charging infrastructure and vehicle sales, with network expansion alleviating range anxiety and improving adoption probability (Li *et al.*, 2017). In this context, consumer incentives and infrastructure investment subsidies are not functionally equivalent, and the marginal adoption effects of different incentive structures vary considerably (Springel, 2021). Structural econometric studies specific to the Chinese market have further demonstrated that the announcements and expectations of subsidy reductions lead to forward shifts in purchase timing and changes in short-term price elasticity, reflecting how the policy time structure influences current demand through expectations (Hu *et al.*, 2025).

1.2 Product Mix and Threshold Structures in Multiproduct Decisions

With integrated decisions on product differentiation, pricing rules, and production capacity allocation as the focus, classical studies on vertical differentiation and product line selection have established the theoretical baseline: in cases where quality is measurable and self-selection constraints are present, the optimal configuration of quality and price has identifiable structural properties. When self-cannibalization of similar products and consumer waiting costs are incorporated into the model, the conditions for sequential introduction with profit advantages over simultaneous introduction can be derived to reveal the threshold structure of coverage and rollout timing (Mussa and Rosen, 1978; Moorthy and Png, 1992). In an expanded setting that considers cost structures, capacity constraints, and competitive interactions, the comparative statics of product line selection, pricing, and output can be systematically derived to provide methodological support for determining the existence, uniqueness, and local stability of equilibrium (Tang and Yin, 2010).

In this framework, regarding NEVs and CEVs as green and brown products, respectively, provides discriminative conditions that are close to industry practices. Research shows that when fixed costs differ, the market is segmented with heterogeneity, and production capacity is limited. Even if the marginal cost of green products is high, hybrid production remains profitable as long as learning effects or the effective scale of the green market can offset the cost disadvantage. However, if the segment is too small or capacity constraints strengthen cannibalization, a single product line is preferred (Yenipazarli and Vakharia, 2015; Agi and Yan, 2020; Yenipazarli and Vakharia, 2017). Thus, pricing, market coverage, and capacity allocation are not independent of one another but are structurally embedded. When key costs or demand parameters approach critical intervals, discontinuous adjustments occur in the equilibrium of the product mix. Corresponding coexistence boundaries and strategy-switching thresholds can be explicitly defined in the parameter space, providing testable structural constraints for empirical identification and policy simulation.

In studies that combine policy and operations, external incentives and original equipment manufacturer (OEM) operational decisions are analyzed within a unified equilibrium framework. Consumer-side measures, such as purchase subsidies and tax exemptions, affect optimal pricing and sales by changing unit economics. Infrastructure-side measures, such as charging station subsidies, improve effective demand by reducing refueling inconvenience and alleviating range anxiety. In markets with indirect network externalities between charging networks and sales, the marginal effects of the two types of incentives on equilibrium sales, social welfare, and output structure are asymmetric. Proper policy combinations can shift the threshold boundaries between hybrid production and product focus (Shi *et al.*, 2022; Yu *et al.*, 2022). Under an automotive industry-specific setting, models incorporating entry and exit choices and category competition intensity show that when cost or network parameters exceed critical thresholds, OEMs may transition directly from a parallel layout of NEVs and CEVs to exclusive NEV production, with differing marginal effects of consumer- and station-side incentives on entry and exit (Pi *et al.*, 2024). In the Chinese regulatory context, models that integrate dual credit and subsidy collaboration into supply chains and operations further demonstrate that policy parameters change the threshold positions of optimal product mix and capacity allocation and their feasible domains by affecting battery technology innovation, charging infrastructure construction, and contract coordination (Xu *et al.*, 2024).

Existing research has created clear analytical frameworks for demand and supply sides. However, with regard to the subsidy exit and tax incentive phase in China, it still has limitations. Demand-side literature typically treated the payment premium for NEV performance attributes as exogenous or static, rarely characterizing its endogeneity with changes in policies and charging network conditions, and modeled it simultaneously with price, demand share, and output structure; as a result, the strategy thresholds and shape constraints of the profit function cannot be easily determined within the same framework. Supply-side research often used static or simplified capacity settings and paid insufficient attention to irreversible fixed costs of production line conversions, learning effects, and the dynamic role of cannibalization within similar products, weakening the global judgment of equilibrium existence, uniqueness, and stability. In addition, research that combined policy and operations often assumed continuous subsidies and lacked a unified characterization of the mechanisms through which tax exemptions and infrastructure investment influence strategy boundaries and welfare distribution in the presence of network externalities. Furthermore, limited systematic tests have been conducted on the threshold conditions for switching from parallel layout to product focus, policy sensitivity, and feasible domains on the basis of data from Chinese firms.

This study provides three main contributions. First, in the post-subsidy context, it constructs a joint decision-making model with consumer premium for NEV performance as the core state variable. It simultaneously solves premium, pricing, demand share, and output ratios in a parameterized demand framework; characterizes the existence and uniqueness conditions of mixed production and single-product strategies; and provides global comparative static and shape constraints for the profit function concerning demand intensity parameters. Second, this study introduces capacity constraints, fixed costs of production line conversion, and constraints on cannibalization on the supply side. It identifies the switching thresholds and coexistence boundaries of product combinations and proves that when key costs or demand parameters cross critical intervals, strategies undergo discrete shifts. It also provides testable identification conditions. Third, through numerical simulation, this research evaluates the sensitivity of key cost elements (such as battery/material costs, fixed costs of production line conversion, and price transmission coefficients) and demand parameters to threshold positions and strategy boundaries and proposes actionable parameter ranges and identification constraints for enterprise product line configuration and policy calibration.

2. Methodology

2.1 Model Construction

Under regulation and industrial policy constraints, qualified automobile manufacturers typically face the scenario of simultaneously producing NEVs and CEVs. With the gradual phase-out of NEV subsidies, consumers' willingness to pay for NEV performance has become a key demand factor driving the linked decisions of production and pricing by enterprises. On this basis, this study constructs a joint decision-making model for maximizing profit and uses it to depict the conditions of consumers' willingness to pay for NEV performance when traditional automobile manufacturers enter the NEV market. It further derives the optimal pricing and production decisions for NEVs and CEVs under different scenarios. To anchor the analysis within management theory, this study adopts SCT as the theoretical framework and defines consumers' willingness to pay for NEV performance as a key environmental parameter. The three possible choices, namely, only CEV, NEV+CEV coexistence, and only NEV, are understood as high-performance configurations that can potentially be achieved in different environmental intervals. This framework further examines how environmental changes affect configuration choices and their alignment with market equilibrium. The key symbols used in this study are summarized in *Table 1*.

Table 1. Model symbols

Symbol	Definition
U_1	Utility of consumers purchasing CEVs
U_2	Utility of consumers purchasing NEVs
U_0	Consumers' willingness to pay for CEVs
$\Delta\gamma$	Performance advantage of NEV over CEV
θ	Premium paid by consumers for the performance preference of NEVs
π	Total profit of the automobile manufacturer
c_1	Production cost of CEV
c_2	Production cost of NEV
q_1	Market share of CEV
q_2	Market share of NEV
β	R&D cost coefficient of NEV
η	Production ratio of NEVs by automobile manufacturers, $q_2^* / (q_1^* + q_2^*)$
Φ	Consumers pay an average premium for the performance preferences of NEVs
p_1	Price of CEV
p_2	Price of NEV

Source: authors' own results.

The overall profit maximization problem for an automobile manufacturer producing CEVs and NEVs is expressed as:

$$\begin{aligned}
&\underset{p_1,p_2}{Max}\ \pi = (p_1 - c_1)q_1 + (p_2 - c_2)q_2 - \beta\Delta\gamma^2 \\
&s.t\ p_2 > p_1 \\
&\quad U_0 \geq c_2 > c_1 \\
&\quad 1 \geq q_1 + q_2 \geq 0
\end{aligned} \tag{1}$$

In the objective function for profit maximization (Equation 1), the constraints specify that the market price of NEVs is higher than that of CEVs, and the initial consumer utility for purchasing is higher than the CEV market price and exceeds the production costs of NEVs and CEVs. The total market share of CEVs and NEVs among the already-purchased consumer group is 1. The basic assumptions of the model are as follows:

(1) A traditional automobile manufacturer produces CEVs and NEVs of similar performance and type simultaneously. This assumption is made because the main difference between CEVs and NEVs lies in the type of fuel used in the vehicles. Manufacturing CEVs and NEVs of the same type allows the manufacturer to reduce the production costs of NEVs, as discussed in the work of Shao, Yang, and Zhang (2017a) and Zheng *et al.* (2018a).

(2) The material cost and market price of CEV production are lower than those of NEV production, and the production costs of CEVs and NEVs are lower than consumers' willingness to pay for purchasing CEVs, as represented by $U_0 \geq c_2 > c_1$, $p_2 > p_1$. This assumption is made because consumers, when making car purchasing decisions, weigh the tradeoffs between CEVs and NEVs and choose either CEVs or NEVs. NEVs have high battery costs in the production process, resulting in a higher market price compared with CEVs, as demonstrated by Shao *et al.* (2017a), Zheng *et al.* (2018a), and Yang *et al.* (2019).

(3) Consumers' willingness to pay for NEV performance preference varies, and this heterogeneity affects consumer preferences for purchasing NEVs and CEVs. This study assumes that consumer heterogeneity in the choice of NEV or CEV is expressed as a willingness to pay a differentiated premium for the superior economic and environmental attributes of NEVs over CEVs (referred to as consumer NEV performance preference premium).

At this point, consumers in the market make purchasing decisions on the basis of the utility they derive from either NEV or CEV of the same model. In accordance with the consumer utility model (Mussa and Rosen, 1978), utility functions for purchasing CEVs and NEVs are established and presented as U_1 and U_2, respectively.

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$$\begin{aligned}
U_1 &= U_0 - p_1 \\
U_2 &= U_0 - p_2 + \Delta\gamma\theta
\end{aligned} \tag{2}$$

where U_0 represents the consumer's willingness to pay for CEV that satisfies the basic driving needs of a particular type of CEV and $\Delta\gamma$ is the performance advantage of NEV over CEV that is mainly reflected in the optimized economic and green performance of NEVs relative to CEVs. Previous studies conducted by Shao *et al.* (2017a), Yang *et al.* (2019), and Zheng *et al.* (2018b) assumed that consumers' willingness to pay, θ , follows a uniform distribution over the interval [0,1]. This study assumes that consumers' willingness to pay a performance preference premium for NEVs follows a uniform distribution over the interval $\left[0,\bar{\theta}\right]$ to facilitate the subsequent discussion of the effects of changes in consumers' willingness to pay for a premium level. The density function is

$$f(\theta)=\begin{cases}\dfrac{1}{\overline{\theta}}, & \theta\in[0,\overline{\theta}]\\ 0, & \theta\notin[0,\overline{\theta}]\end{cases} \tag{3}$$

If $U_1 \geq U_2$ and $U_1 \geq 0$, the consumer will purchase CEV; if $U_2 \geq U_1$ and $U_2 \geq 0$, the consumer will purchase NEV. From Equation (2), the boundary line $\theta_2 = \frac{p_2 - p_1}{\Delta\gamma}$ for choosing to buy a CEV and an NEV can be obtained. Let $U_2 = 0$, and we can obtain $\theta_1 = \frac{p_2 - u_0}{\Delta\gamma}$. Thus, when $\theta \in [0,\ max\{0,\theta_1\}]$, the consumer gives up purchasing NEV and CEV. Meanwhile, when $\theta \in [max\{0,\theta_1\},\ \theta_2]$, the consumer chooses to buy CEV, and when $\theta \in [\theta_2,\ \overline{\theta}]$, the consumer chooses to buy NEV. On the basis of these conditions, the market demand for CEV and NEV can be expressed as

$$\begin{aligned}q_1 &= \int_{max\{0,\theta_1\}}^{\theta_2} f(\theta)d\theta = min\left\{\frac{U_0 - p_1}{2\Delta\gamma\Phi}, \frac{p_2 - p_1}{2\Delta\gamma\Phi}\right\}\\ q_2 &= \int_{\theta_2}^{\overline{\theta}} f(\theta)d\theta = 1 - \frac{p_2 - p_1}{2\Delta\gamma\Phi}\end{aligned} \tag{4}$$

2.2 Model Solution

Given that θ that follows a uniform distribution over $[0,\overline{\theta}]$, consumers' willingness to pay for NEV performance preference premium is assumed to be the average value of consumer NEV performance preference premium and denoted as $\Phi = \frac{\overline{\theta}}{2}$ (hereafter referred to as the payment premium).

By solving the model, we obtain the optimal production strategy, including the corresponding optimal market price, optimal market share, NEV production ratio, and optimal profit, of the automobile manufacturer under different payment premium conditions, as shown in Theorem 1.

(1) When $0 \leq \Phi < \frac{c_2 - c_1}{4\Delta\gamma}$, the optimal production strategy is to produce a single CEV as follows:

$p_1^* = U_0 - 2\Delta\gamma\Phi$, $q_1^* = 1$, $\eta = 1$;

$\pi^* = U_0 - 2\Delta\gamma\Phi - c_1 - \beta\Delta\gamma^2$.

(2) When $\frac{c_2 - c_1}{4\Delta\gamma} \leq \Phi < \frac{2U_0 - c_1 - c_2}{4\Delta\gamma}$, the optimal production strategy is

$$p_1^* = \frac{2U_0 + c_1 - c_2}{2},\ p_2^* = U_0;$$

$$q_1^* = \frac{c_2 - c_1}{4\Delta\gamma\Phi}, q_2^* = 1 - \frac{c_2 - c_1}{4\Delta\gamma\Phi},\ q_1^* + q_2^* = 1,\ \eta = \frac{4\Delta\gamma\Phi + c_1 - c_2}{4\Delta\gamma\Phi};$$

$$\pi^* = U_0 - c_2 + \frac{(c_2 - c_1)(u_0 - c_1)}{8\Delta\gamma\Phi}.$$

(3) When $\frac{2U_0 - c_1 - c_2}{4\Delta\gamma} \le \Phi < \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}$, the optimal production strategy is

$$p_1^* = \frac{2U_0 + 2c_1 - c_2 + 2\Delta\gamma\Phi}{3}, \quad p_2^* = \frac{U_0 + c_1 + c_2 + 4\Delta\gamma\Phi}{3};$$

$$q_1^* = \frac{U_0 - 2c_1 + c_2 - 2\Delta\gamma\Phi}{6\Delta\gamma\Phi}, \quad q_2^* = \frac{U_0 + c_1 - 2c_2 + 4\Delta\gamma\Phi}{6\Delta\gamma\Phi},$$

$$q_1^* + q_2^* = \frac{2U_0 - c_1 - c_2 + 2\Delta\gamma\Phi}{6\Delta\gamma\Phi}, \quad \eta = \frac{4\Delta\gamma\Phi + U_0 + c_1 - 2c_2}{2\Delta\gamma\Phi + 2U_0 - c_1 - c_2};$$

$$\pi^* = \frac{U_0^2 + c_1^2 + c_2^2 - c_1c_2 - U_0(c_2 + c_1)}{6\Delta\gamma\Phi} + \frac{U_0 + 2\Delta\gamma\Phi + c_1 - 2c_2}{3} - \beta\Delta\gamma^2.$$

(4) When $\Phi \ge \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}$, the optimal production strategy is the single production of NEV as follows:

$$p_2^* = \frac{2\Delta\gamma\Phi + U_0 + c_2}{2}, \quad q_2^* = \frac{2\Delta\gamma\Phi + U_0 - c_2}{4\Delta\gamma\Phi}, \quad \eta = 1;$$

$$\pi^* = \frac{(2\Delta\gamma\Phi + U_0 - c_2)^2}{8\Delta\gamma\Phi} - \beta\Delta\gamma^2.$$

Theorem 1 indicates that when the payment premium, Φ is within the interval $\left[0, \frac{c_2 - c_1}{4\Delta\gamma}\right]$, the optimal production strategy for automobile manufacturers is to produce only CEVs. At this point, because the payment premium is low, the automobile manufacturer lowers the price of CEVs to maximize profits, and the market share of CEVs is 1. As payment premium increases, when $\Phi \in \left[\frac{c_2 - c_1}{4\Delta\gamma}, \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}\right]$, the optimal production strategy for automobile manufacturers is to simultaneously produce CEVs and NEVs. In this interval, when $\Phi \ge \frac{2U_0 - c_1 - c_2}{4\Delta\gamma}$, no consumers will abandon purchasing a car, and the overall market share for CEVs and NEVs is 1. However, when , some consumers abandon purchasing a car, and the total market share for NEVs and CEVs is less than 1. When the payment premium is sufficiently large ($\Phi \ge \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}$), the optimal production strategy for automobile manufacturers is to produce only NEVs, and the overall market share for NEVs and CEVs is less than 1.

From the theorem above, we observe the following:

a. For companies under pressure to produce NEVs, if the consumer payment premium is low ($\Phi \le \left(0, \frac{c_2 - c_1}{4\Delta\gamma}\right)$), the company should cooperate with the government to promote and increase the consumer payment premium and reduce the production cost difference between NEVs and CEVs, thereby increasing the performance differences between NEVs and CEVs. This situation will make NEV production one of the optimal decisions and can meet the required production ratio for NEVs.

b. For companies that are not under pressure to produce NEVs, as the consumer payment premium increases, NEV production becomes the optimal decision.

c. For companies under pressure to produce NEVs, our results indicate that stopping the production of CEVs and producing only NEVs is not necessarily the optimal decision. Such decision depends on whether the consumer payment premium is sufficiently large.

2.3 Sensitivity Analysis

In this section, we analyze the effect of payment premium on the optimal production strategy and optimal profit. First, by solving the first-order partial derivatives for the optimal pricing, optimal market share, and NEV production ratio for CEV and NEV, we examine the effect of payment premium on the optimal market share and NEV production ratio. Theorem 2 is derived.

(1) When $0 \le \Phi < \frac{c_2 - c_1}{4\Delta\gamma}$, $\frac{\partial q^*_1}{\partial \Phi}=0$; at this point, if other conditions remain unchanged, as the payment premium increases, the optimal market share for CEVs is still 1.

(2) When $\frac{c_2 - c_1}{4\Delta\gamma} < \Phi \le \frac{2U_0 - c_1 - c_2}{4\Delta\gamma}$, $\frac{\partial q_1^*}{\partial \Phi} < 0, \frac{\partial q_2^*}{\partial \Phi} > 0$; the optimal market share for CEVs decreases as the payment premium rises, whereas the optimal market share for NEVs increases with the increase in the payment premium.

(3) When $\frac{2U_0 - c_1 - c_2}{4\Delta\gamma} < \Phi \le \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}$, $\frac{\partial q^*_1}{\partial \Phi} < 0, \frac{\partial q^*_2}{\partial \Phi} < 0, \frac{\partial (q^*_1 + q^*_2)}{\partial \Phi} = 0$; the optimal market shares for CEVs and NEVs decrease as the payment premium increases.

(4) When $\Phi \ge \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}$, $\frac{\partial q_2^*}{\partial \Phi} < 0$, and $\lim_{\Phi \to +\infty} \frac{2\Delta\gamma\Phi + U_0 - c_2}{4\Delta\gamma\Phi} = \frac{1}{2}$, CEVs exit the market, and the optimal production ratio for NEVs decreases with the increase in the payment premium and eventually approaches 1/2. That is, as increases, the overall market size for automobile consumers eventually shrinks to 1/2.

Theorem 3 is established as follows.

(1) When $\Phi > \frac{c_2 - c_1}{4\Delta\gamma}$ and $\frac{\partial \eta}{\partial \Phi} = 0$, the NEV production ratio increases as the consumer payment premium rises.

(2) When $\Phi \ge \frac{U_0 - 2c_1 + c_2}{2\Delta\gamma}$ and $, \frac{\partial \eta}{\partial \Phi} \ge 0$, the automobile manufacturer produces only NEVs, and the NEV production ratio is 1 and remains unchanged.

Theorems 2 and 3 show that as the payment premium increases beyond the critical threshold ($\Phi > \frac{c_2 - c_1}{4\Delta\gamma}$), the optimal production volume for CEVs decreases, whereas the optimal production volume for NEVs increases, eventually reaching the state where the company's NEV production ratio is 1. At this point, the optimal production strategy is to produce only NEVs and not CEVs. When the manufacturer's optimal strategy is to produce only NEVs, the optimal price for NEVs increases with the payment premium, which in turn raises the market threshold for consumers purchasing NEVs and reduces the overall size of the automobile consumer market. Under the current distribution and external option settings, the overall consumer market share will eventually shrink to 1/2.

Theorem 4 is established as follows: under the condition that other factors remain unchanged, the optimal profit, π^*, for automobile manufacturers is a U-shaped function with respect to the payment premium, and $\Phi=\frac{\sqrt{(U_0-c_1)^2-(U_0-c_2)(c_2-c_1)}}{2\Delta\gamma}$ is the only critical threshold point where the optimal profit changes.

(1) When $\Phi\in\left[0,\frac{\sqrt{(U_0-c_1)^2-(U_0-c_2)(c_2-c_1)}}{2\Delta\gamma}\right]$, an increase in payment premium leads to an increase in optimal profit.

(2) When $\Phi\in\left[\frac{\sqrt{(U_0-c_1)^2-(U_0-c_2)(c_2-c_1)}}{2\Delta\gamma},+\infty\right]$, an increase in payment premium leads to an increase in optimal profit.

Through analysis, we conclude the following:

a. When the payment premium exceeds a certain threshold, that is, $(\Phi\geq\frac{c_2-c_1}{4\Delta\gamma})$, the NEV production ratio of automobile manufacturers initially rises and then stabilizes at 1. Ultimately, the company will reach an equilibrium state where only NEVs are produced, and the market share of NEVs will be less than 1. This situation indicates that consumer payment premiums can drive automobile manufacturers to produce NEVs, and some consumers' abandonment of purchasing CEVs and NEVs decreases the overall demand and retention in the automobile market, thus alleviating the traffic situation in China.

b. When the payment premium exceeds a certain threshold, that is, ($\Phi\geq\frac{c_2-c_1}{4\Delta\gamma}$), the optimal price for NEVs increases as the payment premium rises, and eventually, the optimal strategy will be to produce only NEVs. This condition indicates that after the subsidy policy exits the market, consumer payment premiums may become a new driving force for automobile manufacturers to produce new energy vehicles.

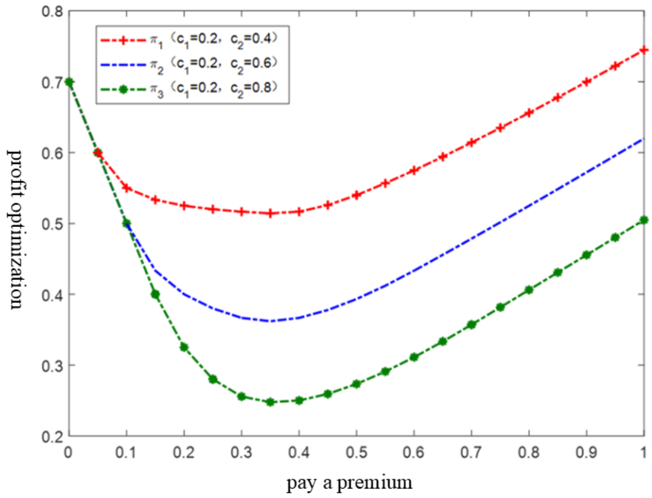
c. The optimal profit for automobile manufacturers has a U-shaped relationship with the payment premium. When the payment premium is at a low level, producing NEVs causes the company's optimal profit to decline. As consumers' willingness to pay for NEVs continues to increase and exceeds the critical threshold, the optimal profit increases with the payment premium. This situation reflects the notable effect of consumer payment premiums on the company's optimal profit. Companies should conduct detailed market research on consumer payment premiums to optimize production decisions.

3. Numerical Simulation

This section presents numerical simulations conducted based on the analysis results above. These simulations examine the effect of consumers' NEV performance preference payment premiums on the optimal prices, optimal market shares, and overall optimal profit of NEV and CEV automobile manufacturers.

In this study, the overall market size for NEVs and CEVs is assumed to be 1. Therefore, the production costs of NEVs and CEVs are standardized to the range of (0, 1). First, the effects of payment premium and changes in NEV production material costs on the optimal profit are analyzed. With reference to the model specifications of

Cheng, Wang, and Gong (2018), the values are assigned as follows: (1) high NEV production material costs: $c_1 = 0.2$ and $c_2 = 0.8$, (2) moderate NEV production material costs: $c_1 = 0.2$ and $c_2 = 0.6$, and (3) low NEV production material costs: $c_1 = 0.2$ and $c_2 = 0.4$. These settings are shown in *Figure 1*.

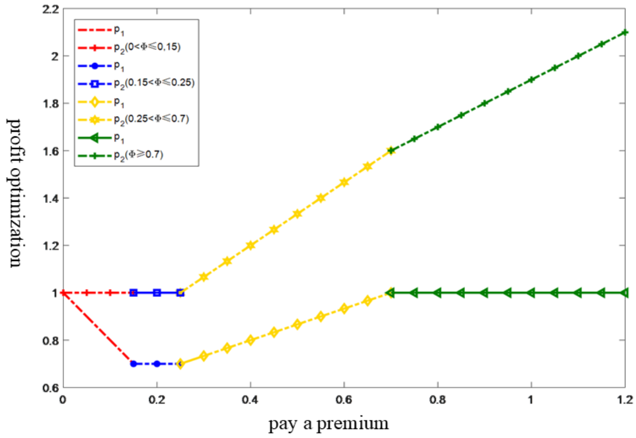


Source: created by the authors.

Figure 1. **Optimal Profit under Differences in the Production Costs of NEVs and CEVs**

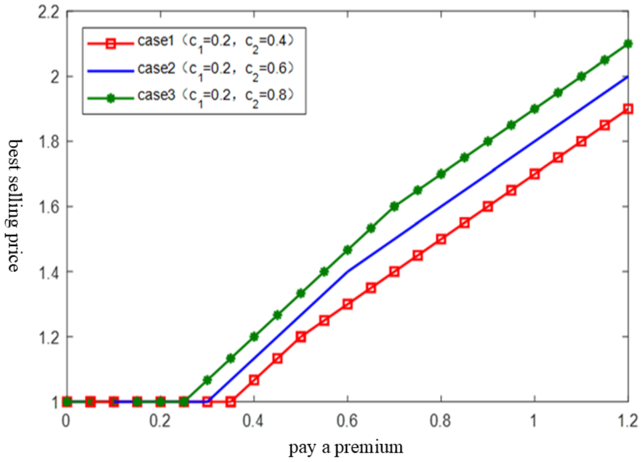
Figure 1 shows the effect of payment premium at different NEV production material cost levels on the optimal profit for automobile manufacturers. As the payment premium increases, the overall profit of automobile manufacturers decreases then increases. As the material cost (c_2) of NEVs decreases, an increase in payment premium leads to high profit levels for manufacturers, suggesting that reducing NEV production material costs positively affects the optimal profit of manufacturers.

Next, we analyze how the optimal prices for CEVs and NEVs vary with the payment premium at different NEV production material cost levels. The model values are similar to those before. *Figure 2* shows that the price gap between NEV and CEV increases with the payment premium. As the payment premium increases, the optimal market price for NEVs shows a continuous upward trend. *Figure 3* demonstrates that after the payment premium reaches a certain level, the optimal price for NEVs increases as the payment premium rises. When the payment premium decreases, the rate of increase in the optimal price (c_2) of NEVs slows down, indicating that c_2 's reduction of the payment premium has a positive effect on the optimal price of NEVs.



Source: created by the authors.

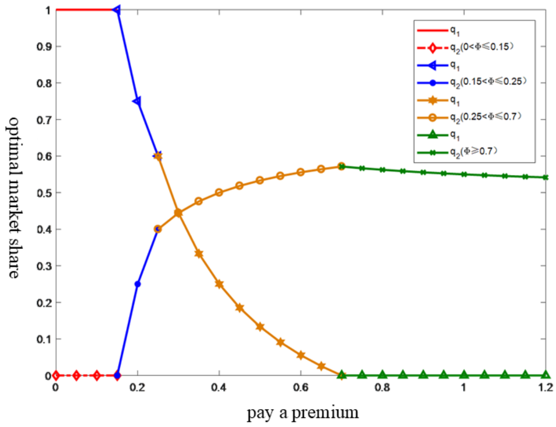
Figure 2. **Optimal Selling Prices of NEVs and CEVs under Different Payment Premiums**



Source: created by the authors.

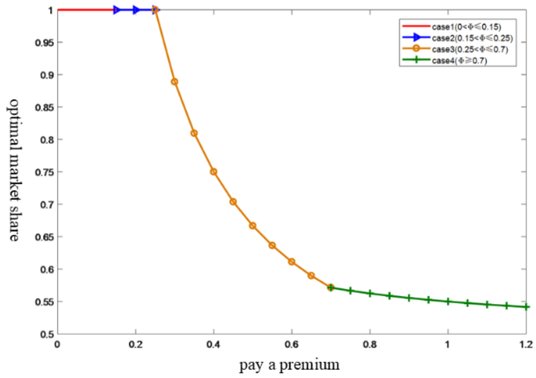
Figure 3. **Optimal Selling Price of NEV under Varying Production Cost Differences**

Next, the influence of payment premium on the market shares of CEVs and NEVs and on the NEV production ratio is analyzed. The model values assume high NEV production material costs, namely, $c_1 = 0.2$ and $c_2 = 0.8$. *Figures 4* and *5* show that an increase in the payment premium leads to a rise in the optimal market share of CEVs. The optimal market share for NEVs initially rises and then declines as the payment premium increases, eventually stabilizing. *Figure 6* indicates that after the payment premium reaches a certain level, the NEV production ratio increases with the payment premium and subsequently stabilizes, remaining constant at 1. This finding demonstrates the substitutability of NEVs for CEVs under different payment premium conditions.



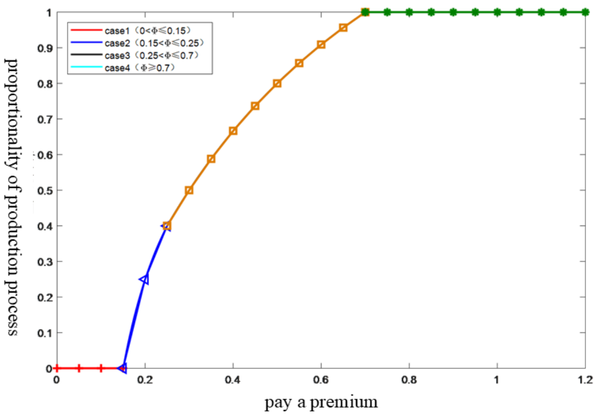
Source: created by the authors.

Figure 4. **Optimal Market Shares of CEVs and NEVs under Different Payment Premiums**



Source: created by the authors.

Figure 5. **Overall Market Share under Different Payment Premiums**



Source: created by the authors.

Figure 6. **Production Ratio of NEV under Different Payment Premiums**

4. Discussion

This section provides an academic interpretation of the mechanisms revealed by the model and summarizes the findings into three key points. Each point is positioned within the existing theoretical framework and offers testable empirical propositions.

First, the threshold mechanism driven by the payment premium determines when and to what extent production will switch. The results show that the optimal product mix for the firm is divided into clear intervals on the basis of the payment premium within the parameter space, with discrete changes in price and product line at the boundary. This structure elevates the traditional binary choice problem to a recognizable threshold determination and transition prediction issue, providing two directly testable phenomena: the concentration of model types at the boundary and the discontinuous expansion of the NEV and CEV price gap. This mechanism aligns with vertical differentiation frameworks regarding market coverage thresholds and the sequence of product line introduction and exit, thereby offering empirical identification anchors for threshold locations and strategy transition magnitudes (Mussa and Rosen, 1978; Moorthy, 1984; Moorthy and Png, 1992; Shaked and Sutton, 1982).

Second, market size convergence arises from the increase in the participation threshold by optimal pricing, where the external environment primarily shifts the threshold location rather than directly altering the direction. When the payment premium approaches and surpasses the internal critical point of the mixed interval, upward adjustment of optimal pricing causes marginal consumers to exit, leading to convergence in market size rather than expansion. Thus, the increase in the adoption rate and market size changes is systematically distinguished in the mechanism; the former is driven by the payment premium crossing the threshold, and the latter depends on the threshold position and its relative relationship with the affordability boundary. Network and policy factors (charging accessibility and tax incentives) mainly affect the difficulty of crossing the threshold by shifting its location, which aligns with the evidence on indirect network externalities and price elasticity in the electric vehicle market (Li *et al.*, 2017; Springel, 2021; Alsharif, 2025). Therefore, empirical identification should simultaneously test for threshold crossing and threshold displacement, examining the discreteness of model substitution and price gap changes near the threshold.

Third, the U-shaped profit path provides a structured explanation for the phase coexistence of dual product lines and generates testable comparative statics under cost shocks. In low to moderate premium intervals, profits initially decrease and then increase, and after crossing the unique turning point, they rise with the payment premium. This non-monotonicity explains early coexistence as a rational response to threshold uncertainty, rather than merely a transitional arrangement. Key cost reductions (battery and materials) should shift the threshold leftward and prompt an early transition, manifesting in an overall upward shift in the profit curve and time concentration of product line adjustments. Embedding these shape constraints into structural demand estimation allows for the identification of premium intensity and threshold location via the linkage of price, market share, and margin, thereby translating the mechanistic proposition into an actionable empirical design (Yenipazarli and Vakharia, 2015; Yenipazarli and Vakharia, 2017; Agi and Yan, 2020; Berry, Levinsohn and Pakes, 1995; Berry and Haile, 2014).

Conclusions and Implications

Conclusions

The NEV industry is the key to realizing high-quality, sustainable development in China's automotive sector and achieving emission reduction and energy security. Drawing on the research of Shao *et al*. (2017) and Zheng *et al.* (2018) regarding subsidy phase-out, this study examines the mixed production decisions of traditional automobile manufacturers in the context of subsidy exit. A joint decision model for product mix and pricing is developed by considering NEV and CEV pricing as joint decision variables and incorporating consumers' willingness to pay for NEV performance. The study characterizes optimal production strategies in different premium intervals and their transition thresholds, providing criteria for whether and when firms should enter NEV production, followed by numerical analysis to verify the main theoretical propositions. The following conclusions were derived.

(1) After consumers' willingness to pay for NEV performance is incorporated into demand, the firm's optimal product mix exhibits three distinguishable segments: production of only CEVs in low-premium intervals, mixed production of NEVs and CEVs in moderate-premium intervals, and production of only NEVs in high-premium intervals.

(2) Comparative static analysis of payment premiums shows that the market share and production ratio of NEVs increase monotonically with the premium. When the premium surpasses the internal threshold of the mixed interval, the optimal strategy switches to producing only NEVs, and the equilibrium market size is halved.

(3) The firm's optimal profit exhibits a U-shape relationship with payment premium, with a unique turning point. A reduction in key costs causes the threshold to shift leftward, prompting an early transition and resulting in an upward shift in the profit curve.

Managerial Implications

This study has the following managerial implications.

First, a joint decision mechanism centered on consumers' willingness to pay for a premium should be established. Firms should regularly monitor consumers' willingness to pay for NEVs and identify different threshold intervals on this basis. Product mix and pricing strategies should be designed for each interval. The focus on traditional fuel models in the low-premium interval should be maintained, and small-scale testing should be conducted. Controlled mixed production should be implemented, the price difference between the two models in the moderate-premium interval should be managed, and the focus should be entirely on NEV production in the high-premium interval. To avoid misjudging critical points, we should set clear trigger and response rules by using price, market share, and marginal profit as decision thresholds and by clearly defining the timing and extent of model addition and discontinuation and price adjustments.

Second, threshold uncertainty should be avoided by using flexible production capacity and staged investment. Risks of strategy switches and profit fluctuations exist near the threshold. Manufacturers can enhance assembly flexibility through platformization and modularization, retain dual-line redundancy and reversible transition capabilities, and integrate the procurement of key materials and capacity adjustments into phased contractual arrangements. In addition, small batch prototyping and stage reviews can create a rhythm of pilot–validation–expansion, quickly scaling up after crossing the threshold while avoiding the opportunity cost caused by prematurely shutting down or blindly expanding.

Third, operational measurement and experimental evaluation framework based on shape constraints should be built. The interrelationships among price, market share, and margin; the time concentration of model adjustments; and the turning points of profit curves should be solidified as operational metrics and early warning thresholds for identifying strategy switching windows. Regional contrast experiments should be conducted on critical intervals to assess the marginal effects of price adjustments and changes in product mix on market size and profit. On the basis of the experimental results, dynamic updates to cost parameters and threshold estimates should be made, allowing for timely calibration of production scheduling, pricing, and model sequencing in response to changes in payment premiums.

Limitations and Future Directions

This study still has several limitations that need further exploration. First, the model setup is simplified. This study uses a single firm, static equilibrium, and a given preference distribution without explicitly incorporating usage-stage costs and quality uncertainty. Future research could integrate factors, such as battery degradation, battery swapping or charging time costs, maintenance, and insurance, into the utility function while relaxing assumptions about the distribution and heterogeneity of payment premiums. Second, competition and supply constraints are not explored in this study. Oligopolistic competition, entry and exit, irreversible production capacity, learning curves, and supply chain coordination are also not considered. Future work could systematically evaluate the substitution and complementary effects of dual credit and tax incentives under different market structures and identify threshold shifts and strategy switching differences. Last, empirical validation needs to be strengthened. Currently, verification mainly relies on numerical simulation. Future studies should combine model-level pricing and sales data with cost and infrastructure data and conduct event studies and structural estimation by using policy or cost shocks to test propositions, such as threshold location, switching points, price gap transitions, and market size convergence. Then, counterfactual and welfare evaluations should be conducted on the basis of the results.

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VEIKLOS STRATEGIJA PASIBAIGUS SUBSIDIJOMS: KAINODAROS IR PRODUKTŲ LINIJŲ SPRENDIMAI ELEKTRINIŲ BEI TRADICINIŲ TRANSPORTO PRIEMONIŲ MODELIAMS

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Santrauka. Atsižvelgusi į anglies dioksido emisijų viršūnės pasiekimą ir neutralumo tikslus bei automobilių pramonės transformaciją, Kinija pradėjo laipsniškai mažinti naujų energijos transporto priemonių (NEV) subsidijas, taip reikšmingai susilpnindama išorines paskatas. Tradicinių automobilių gamintojai, turintys teisę gaminti NEV, privalo priimti gamybos sprendimus derindami naujų energijos transporto priemonių ir vidaus degimo varikliais varomų automobilių apimtis, taip pat atsižvelgdami į jų eksploatacijos rodiklius. Šie sprendimai tiesiogiai veikia efektyvią transformaciją ir stabilų pelną. Tačiau esamuose tyrimuose, nagrinėjančiuose laipsnišką subsidijų panaikinimą, nepakankamai dėmesio skiriama veiksmingoms slenkstinių gamybos sprendimų taisyklėms ir standartizuotoms analitinėms sistemoms, taikomoms gamybos operacijų bei tiekimo grandinių konfigūracijai. Remiantis struktūrinės atsitiktinės padėties teorija, sukurtas bendras sprendimų priėmimo modelis, orientuotas į pelno maksimizavimą, siekiant ištirti, kaip vartotojų priemokos už NEV našumą, pasikeitus paklausos struktūrai po subsidijų panaikinimo, veikia optimalią mišrią gamybą ir bendrą kainodarą. Siekiant apibūdinti optimalių sprendimų reakciją į pagrindinius parametrus, buvo atliktas statinės pusiausvyros išvedimas ir lyginamoji statinė analizė, o slenksčių nustatymas pasitelktas kritinėms strategijos keitimo sąlygoms apibrėžti. Rezultatai atskleidė, kad: (1) vartotojų priemokos lygis teigiamai koreliuoja su NEV gamybos dalimi; kai priemoka yra mažesnė už tam tikrą slenkstį, gamintojai gamina tik įprastas transporto priemones, o ją viršijus pereinama prie mišrios gamybos; pasiekus aukštesnį slenkstį, gaminamos tik NEV; (2) didėjant vartotojų priemokai, bendras automobilių pirkėjų skaičius mažėja ir galiausiai stabilizuojasi maždaug perpus mažesniame lygyje nei pradinis; (3) optimalus gamintojo pelnas su vartotojų priemoka susijęs U formos ryšiu, t. y. pelnas iš pradžių mažėja, o vėliau didėja. Išvadose pateikiama metodologinė nuoroda ir politikos įžvalgos, kaip automobilių gamintojams subalansuoti pelno stabilumą ir technologijų sklaidą žaliosios pertvarkos metu.

Reikšminiai žodžiai: operacijų valdymas; gamyba ir kainodara; mišri gamyba; naujos energijos transporto priemonės; subsidijų panaikinimas.