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HOW DO GOVERNMENT SUBSIDIES INFLUENCE PRICING STRATEGIES AND MARKET EQUILIBRIUM IN THE ELECTRIC VEHICLE INDUSTRY?

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Abstract. Against the background of the low-carbon transition and rapid electrification of road transport, this study examines strategic interaction between an electric vehicle (EV) manufacturer and a fuel vehicle (FV) manufacturer under alternative government subsidy mechanisms. We compare three policy scenarios, *i.e.*, no subsidy, a fixed lump-sum subsidy, and a quantity subsidy. The findings show that the fixed subsidy neither affects equilibrium prices nor quality investment, it only transfers profit to the EV manufacturer. The quantity subsidy increases quality investment and can improve profits for both manufacturers when the subsidy intensity is moderate. It further shows that subsidies become inefficient when the investment coefficient is low, and the effectiveness depends on the EV–FV cost difference. These results reveal analytical and managerial insights for the design of EV subsidy policies.

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1. Introduction

In recent years, electric vehicles have been moving towards electrification, intelligent mobility, and a sustainability transition, which is supported by government policies that accelerate adoption and technological upgrading [1]. However, limited battery lifespan and long charging times llimit EVs' market expansion and weaken their competitiveness relative to fuel vehicles [2].

To sustain EV market growth, governments worldwide implemented subsidy programs and related policy incentives. Evidence from the UK shows that although some EVs are approaching cost parity with conventional vehicles, subsidies remain important in the short term to accelerate adoption and support transport decarbonization [3]. Such support is also important for preserving EVs' competitive position during the transition period [4]. More broadly, the shift from FVs to EVs generates substantial environmental benefits by reducing emissions and reducing dependence on fossil fuels [5].

Moreover, governments in both developed and developing economies are promoting vehicle electrification to strengthen future manufacturing competitiveness. In China, policy support includes financial incentives, tax preferences, technology programs, consumer subsidies, and production mandates for automakers [6]. At the same time, local governments also developed policy mechanisms to support the adoption of new energy vehicles [7].

Keywords. Electric vehicle, fuel vehicle, government subsidy, sustainable development, market equilibrium.

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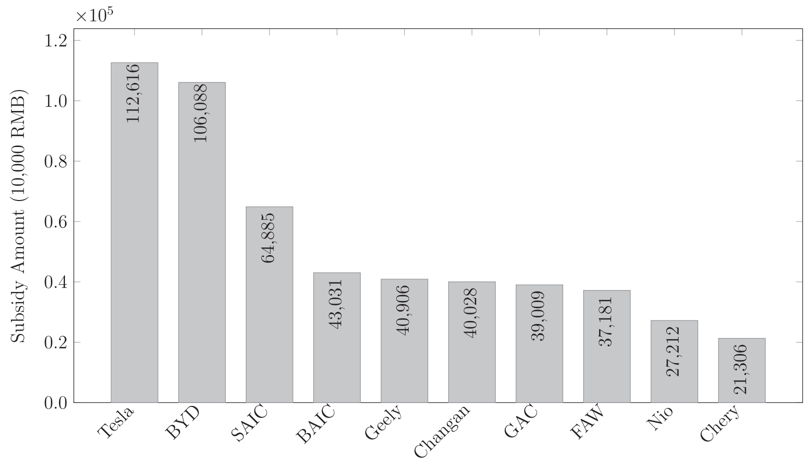

FIGURE 1. Subsidy amounts for the top 10 electric vehicle enterprises in China for 2024.

Similarly, the United States and the European Union increasingly treat electrification as an industrial strategy tied to battery supply chains, semiconductors, and next-generation mobility. Recent research further shows that allocating public support between vehicle deployment and charging infrastructure remains a central policy challenge [8]. This evidence presents the importance of designing economically disciplined and strategically effective subsidy policy. Since the introduction of purchase subsidies for EVs in 2009, the industry has experienced steady and rapid growth, establishing China as the world's largest producer and consumer of EVs.[1] Currently, the Chinese government continues to implement the vehicle purchase tax exemption/reduction policy for new energy vehicles through the end of 2027, with full exemption in 2024–2025 and a 50% reduction in 2026–2027.[2] (Announcement No. 10 [2023]).

According to the *Ministry of Finance of the People's Republic of China*, approximately 7 billion RMB was allocated in 2024 for the settlement of subsidies for new energy vehicles promoted in 2022 and for advance payments covering vehicles already promoted but not yet fully settled.[3] Figure 1 lists the top 10 EV enterprises receiving allocations under this notice. Chinese subsidy policies have primarily taken two distinct forms. The first is fixed lump-sum subsidies, typically implemented as one-time rewards for corporate R&D investments (such as special funds for R&D and technological innovation), which provide a predetermined amount of funding independent of actual sales. The second is quantity subsidies, which are determined directly by sales volume, thereby tying government support to market performance.

In parallel, Europe and North America have intensified their support for EVs [9]. The diversity of subsidy instruments and their implications for industrial competition make it important to understand how such policies affect both EV and FV manufacturers [5, 10]. Sheldon *et al.* [11] show that, despite their fiscal cost, plug-in

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[1]Ministry of Finance of the People's Republic of China, Notice on Improving Financial Subsidy Policies for the Promotion and Application of New Energy Vehicles (Cai Jian No. 86 [2020]), Notice on Financial Subsidy Policies for the Promotion and Application of New Energy Vehicles in 2022 (Cai Jian No. 466 [2021]).

[2]The Chinese government announced that the vehicle purchase tax exemption/reduction policy for new energy vehicles would be extended through December 31, 2027. The policy provides full exemption for vehicles purchased during 2024–2025 and a 50% tax reduction for vehicles purchased during 2026–2027. Ministry of Finance, State Taxation Administration, and Ministry of Industry and Information Technology of the People's Republic of China, Announcement on Extending and Optimizing the Vehicle Purchase Tax Exemption and Reduction Policy for New Energy Vehicles.

[3]Ministry of Finance of the People's Republic of China. Notice on Allocating the 2024 Energy Conservation and Emission Reduction Subsidy Fund Budget (First Tranche), Cai Jian [2024] No. 58. The notice specifies that these funds are used for the settlement of 2022 new energy vehicle promotion subsidies and for advance allocation for vehicles already promoted but not yet fully settled.

electric vehicle subsidies remain an important driver of adoption and emissions reduction in the medium run. Asgarian *et al.* [12] likewise emphasize that subsidy policy must be evaluated together with broader transport and energy policy instruments.

Although subsidy policies have significantly accelerated the development of the EV industry and narrowed the gap between EVs and FVs, consumers still consider a series of factors when purchasing a vehicle. Consumers are attracted to EVs due to their advanced intelligent control systems, significantly reduced noise levels, and lower operating and maintenance costs [13], as well as to FVs due to convenience [14]. The perceived value of EVs and FVs varies among consumer groups. Hence, understanding these differences is key to promoting wider EV adoption.

Recognizing the importance of consumer preferences and manufacturer strategy, this study develops a game framework to analyze which subsidy mechanisms affect price competition, quality investment, and firm profits in the vehicle market. We compare three policy mechanisms: no subsidy, a fixed subsidy, and a quantity subsidy. The framework provides an analysis basis for assessing different subsidy policies.

This study explores the following key questions.

(1) How does the EV manufacturer's quality investment affect consumer valuation and market equilibrium under different subsidy policies?
(2) How do differences in manufacturing costs influence the development of the EV and FV industry?
(3) What are the optimal strategic responses of EV manufacturers to different government subsidy mechanisms?
(4) Which type of subsidy policy is most effective in promoting the sustainable development of the EV industry?

To answer these questions, we study a duopoly game in which an EV manufacturer and an FV manufacturer compete in price, while the EV manufacturer chooses quality investment. The analysis reveals three main findings. First, a fixed subsidy does not affect equilibrium prices or quality investment relative to the no-subsidy benchmark. It mainly acts as a transfer to the EV manufacturer. Second, a quantity subsidy increases quality investment in equilibrium. When properly calibrated, it can also improve the profits of both firms. Third, the effectiveness of both subsidy types depends on the cost difference between EVs and FVs. Subsidies work only when this difference is moderate. They become ineffective when the investment coefficient is low.

This study is organized as follows. Section 2 reviews the relevant literature and identifies the research gap. Section 3 introduces the model and the three subsidy mechanisms. Section 4 compares the resulting equilibria, and Section 5 concludes with the main findings and policy implications.

2. Literature review

This section reviews the literature on government subsidy strategies and operational decisions in the automotive industry.

2.1. Government subsidy policies

Prior studies show that EV subsidies can stimulate industrial growth and accelerate the adoption of sustainable technologies [15,16]. Both production- and consumption-level subsidies have fostered innovation within China's EV sector [17, 18]. Government interventions, including subsidies, tax incentives, and procurement contracts, have supported the development of domestic EV brands and helped these firms adapt to changing market demand. These measures have also attracted younger car buyers in China and contributed to the rapid expansion of the EV market [19].

Among these interventions, purchase subsidies are widely used because they reduce consumers' upfront costs. However, they also impose fiscal costs on governments [20]. For example, Wang *et al.* [21] showed that subsidies increase consumers' willingness to pay in the U.S. EV market, and related studies report similar evidence for China. When the Chinese government reduced its EV subsidies in June 2019, BYD experienced a 7.4% decline in sales [22], suggesting that EV demand is sensitive to subsidy policy during the early stage of market development. Sheldon [23] examined how the cost-effectiveness of the U.S. federal plug-in EV subsidy program evolved over time and assessed whether additional subsidies are needed to attract middle- and low-income consumers rather than mainly wealthy buyers. Moreover, Shi *et al.* [24] developed an evolutionary game model involving the government, consumers, and energy vehicle manufacturers to study NEV diffusion under subsidies, environmental constraints, and consumers' low-carbon preferences.

Government support also affects EV infrastructure development, which in turn shapes the long-run growth of the industry. In particular, prior work recommends additional investment in charging-station construction [25]. One example is Hong Kong's $3.5 billion "EV-charging at Home Subsidy Scheme" (EHSS), which subsidizes the installation of EV charging-enabling infrastructure (EVCEI) in existing private residential buildings. The program expands charging access and lowers one barrier to EV adoption.[4]

Recent studies examined how different policies affect EV adoption. For example, the dual credit system and targeted subsidies influence market behavior and production decisions [26–28]. Sun [29] and Zhao *et al.* [30, 31] suggest that carbon trading mechanisms and consumer education also affect the adoption of environmentally friendly vehicles. These studies indicate that subsidy policies may be more effective when combined with measures that improve public awareness. Burra *et al.* [32] analyzed EV subsidies in Germany and found high free-ridership rates, indicating that many buyers would have purchased EVs even without subsidies. The cost per induced BEV was substantially higher for company cars, which account for 55% of new BEV sales.

Although this study focuses on the EV market, evidence from other industries also provides useful experience. For example, Pan *et al.* [33] analyzed the effects of subsidies in the hydrogen energy supply chain, while Zhang *et al.* [34] found that subsidies may also generate adverse effects in the biomass power supply chain. Xu *et al.* [35] developed a solar sheep game model and reported that feed-in tariffs maximize government revenue. These studies show that subsidy design affects both economic and environmental outcomes across different low-carbon industries.

2.2. Optimal operational strategies

The automotive industry has become increasingly competitive in recent years. It is driven by rapid technological progress and changing consumer preferences. To maintain competitiveness and achieve long-term success, firms must adopt effective operational strategies. These strategies should focus on key challenges, including improving production efficiency and investing in product quality that enhances consumers' perceived utility [36].

In this context, many studies have examined the impact of subsidy policies on the EV industry. For example, Gu *et al.* [37] suggested that subsidies should target consumers in the early stages of the EV market and gradually shift toward manufacturers as the market grows and policy budgets increase. They also found that subsidies become less effective as the market develops, mainly because of market saturation. Building on this view, Gao *et al.* [17] ponted out that subsidies for EV manufacturers are more effective than consumer price discounts. Their study shows that manufacturer subsidies can achieve EV sales and social welfare levels similar to those under government subsidies, while greatly reducing government spending.

Additionally, Jie *et al.* [22] showed that technology assistance programs can complement subsidy and tariff policies in developing countries. These programs can support domestic EV development, reduce EV prices, and benefit both consumers and manufacturers through technology spillovers. Moreover, Liu *et al.* [38] demonstrated that the effectiveness of greenness-based EV subsidy (GEVS) policies depends on both subsidy thresholds and consumer environmental preferences (CEPs). Specifically, their study found that low subsidy thresholds can boost profits and mitigate environmental impacts when CEPs are weak. However, when CEPs are strong, the same low thresholds may produce the opposite outcome by diminishing profits and increasing environmental harm.

In addition, several studies employed evolutionary game theory to examine the dynamic interactions between government policy and industry development. For example, Ji *et al.* [39] found that this approach can support

[4]The government has launched a $3.5 billion "EV-charging at Home Subsidy Scheme" ("EHSS") to subsidize the installation of electric vehicle charging-enabling infrastructure ("EVCEI") in car parks of existing private residential buildings. https://www.evhomecharging.gov.hk/en.

TABLE 1. Literature review.

Literature	Game theory	Production cost differences	Consumer subsidy	Production subsidy		Quality/Perceived utility
				Quantity subsidy	Fixed subsidy	
Deng *et al.* [43]	✓				✓	
Gu *et al.* [37]	✓		✓			
Yu *et al.* [26]	✓		✓			
Zhu *et al.* [44]	✓				✓	
Gao *et al.* [17]	✓		✓	✓		
Shi *et al.* [25]	✓		✓			
Wang *et al.* [16]			✓			
Zhu *et al.* [45]	✓				✓	
Chen *et al.* [27]	✓			✓		
Pan *et al.* [33]	✓			✓		
Zhang *et al.* [34]	✓		✓			
This paper	✓	✓		✓	✓	✓

long-term growth in the EV industry by stabilizing the market and enabling a gradual transition in policy. Liao *et al.* [40] compared static and phased carbon tax policies, showing how carbon trading revenue, charging infrastructure, tax incentives, and consumer preferences affect equilibrium. For example, Chakraborty *et al.* [41] found that combining EV subsidies with green taxes on gasoline vehicles generates greater social welfare and better environmental outcomes than implementing either policy alone. Similarly, Jin *et al.* [42] showed that a dynamic dual credit policy can support NEV development while reducing regulatory costs.

2.3. Gaps and contributions

This study aims to address gaps in the literature by analyzing government subsidy policies within the automotive industry. The key differences between this study and previous research are summarized in Table 1.

The literature review presents the effects of different government subsidy policies, and there is still lack of comparison of the effects of different subsidy strategies. This gap hampers our understanding of how different policies affect the vehicle market. To address this, this study explores three subsidy scenarios, analyzing their impact on the profitability of EV manufacturers and FV manufacturers, as well as on vehicle pricing strategies.

This study makes three main contributions: (1) It establishes a unified game model framework to compare three subsidy policies, allowing for a consistent analysis of different scenarios. (2) It identifies the Nash equilibrium conditions for each policy, demonstrating how the investment coefficient (η), the cost difference between EVs and FVs (m), and the subsidy level (s) interact to influence the market. Interestingly, the study finds that fixed lump-sum subsidies do not alter quality investment or retail prices compared to having no subsidies at all. (3) It provides clear policy recommendations, indicating that quantity subsidies are most effective in encouraging investment in product quality. Additionally, policymakers need to adjust the subsidy level based on the cost difference, as subsidies become ineffective when the cost difference is either too large or too small.

3. MODEL

3.1. Problem description

To promote sustainable growth in the EV industry, governments frequently provide financial incentives to manufacturers. Such interventions are intended to encourage R&D investment, accelerate production expansion, and strengthen technological competitiveness. We examine the effects of alternative subsidy mechanisms by comparing three strategic decision settings. Figure 2 illustrates the sequence of decisions in each game scenario.

As illustrated in Figure 2, M_1 and M_2 denote the FV and EV manufacturers, respectively. The EV manufacturer can invest in product quality and technology enhancement to raise the perceived attractiveness of the

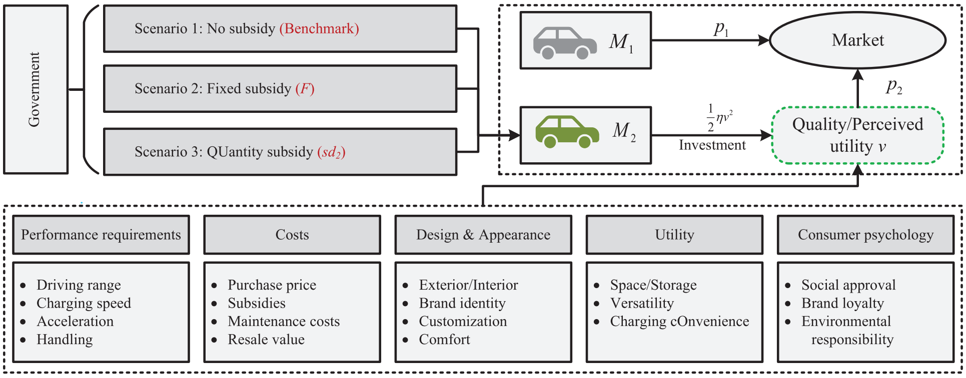


FIGURE 2. Game frameworks for different scenarios.

EV and expand market demand. In practice, such investment may take the form of improvements in battery performance, driving range, intelligent systems, or production efficiency.

To support such quality enhancing activities, governments may subsidize EV manufacturers in different ways. Scenario 1 is the benchmark with no subsidy. Scenario 2 introduces a fixed subsidy to the EV manufacturer. Scenario 3 considers a quantity subsidy for EV sales. Table 2 summarizes the notation used in the analysis.

To analyze competition behavior and the effects of policy on quality improvement, we use a linear demand function to capture these factors. It can maintain the key interactions among prices, substitution, and EV quality investment. The demand functions are defined as $d_1 = a - p_1 + bp_2$ and $d_2 = a - p_2 + bp_1 + \theta v$, where d_1 and d_2 represent the demands for FVs and EVs, respectively.

$$\begin{cases} d_1 = a - p_1 + bp_2 \\ d_2 = a - p_2 + bp_1 + \theta v \end{cases} \tag{1}$$

where a denotes potential market demand, b captures substitution between the two products, v denotes EV quality investment, and θ measures the responsiveness of EV demand to that investment.

The decision variable v is interpreted as the endogenous quality investment made by the EV manufacturer. This investment directly influences consumer willingness by enhancing vehicle attributes. Therefore, consumer perception reflects the response to quality improvement, rather than acting as a separate decision variable. Consumer heterogeneity is summarized by a single sensitivity parameter θ, which captures the average market response to improvements in EV quality.

As EV manufacturers invest more in technological advancements, such as green battery technologies and intelligent driving systems, the marginal cost of investment tends to increase. This observation aligns with findings from recent studies [46,47]. To model this relationship, the cost of quality investment is represented by the quadratic function $C(v) = \frac{1}{2}\eta v^2$, where $C(v)$ denotes the investment cost function for improving EV quality, and η is a coefficient reflecting the marginal cost associated with increasing quality-enhancing efforts. Based on these assumptions, the following sections will calculate the optimal equilibrium solutions under different subsidy scenarios and further analyze the effectiveness of various subsidy policies in the automobile market.

3.2. Different subsidy scenarios

Based on the previous assumptions, we introduce and analyze three game scenarios: the no-subsidy scenario, the fixed-subsidy scenario, and the quantity subsidy scenario.

TABLE 2. Explanation of model variables and symbols.

Symbol	Explanation
a	Potential demand, where $a > 0$.
b	Price sensitivity coefficient measuring the degree of substitutability between EVs and FVs; a higher b indicates stronger competitive interaction between the two products, where $b \in (0, 1]$.
θ	Consumer preference coefficient capturing the sensitivity of EV demand to the manufacturer's product quality investment v; a higher θ implies that consumers place greater weight on product quality relative to price, where $\theta \in (0, 1]$.
η	Manufacturer's investment cost coefficient, reflecting the marginal cost of increasing the quality investment level v; a higher η implies diminishing returns to quality investment, where $\eta > 0$.
F	Government's fixed subsidy amount to electric vehicle manufacturers, where $F > 0$.
s	Government's subsidy amount to electric vehicle manufacturers based on the quantity, where $s > 0$.
c_1	Product cost of the fuel vehicle, where $c_1 > 0$.
c_2	Product cost of the electric vehicle, where $c_2 > 0$.
m	Production cost differential between the EV and FV, defined as $m = c_2 - c_1$; a positive m indicates that EVs are currently more costly to produce than FVs, where the sign and magnitude of m critically shape equilibrium outcomes under each subsidy regime.
π_1	Profit of the fuel vehicle manufacturer, where $\pi_1 > 0$.
π_2	Profit of the electric vehicle manufacturer, where $\pi_2 > 0$.
Decision variables	
v	The EV manufacturer's product quality investment level, which improves observable EV attributes and thereby enhances consumers' perceived utility and stimulates demand, where $v > 0$.
p_1	Price of the FV, where $p_1 > 0$.
p_2	Price of the EV, where $p_2 > 0$.

Notes: The superscripts $\mathrm{s1}, \mathrm{s2}, \mathrm{s3}$ correspond to the three game scenarios, respectively.

3.2.1. Scenario 1: No subsidy (benchmark model)

In the benchmark scenario, the government does not provide financial subsidies to electric vehicle manufacturers. Consequently, the profit functions of the two automakers are expressed as follows:

$$\begin{cases} \max\limits_{p_1} \pi_1^{\mathrm{s1}} = d_1(p_1 - c_1) = (a - p_1 + bp_2)(p_1 - c_1), \\ \max\limits_{p_2, v} \pi_2^{\mathrm{s1}} = d_2(p_2 - c_2) - \dfrac{1}{2}\eta v^2 \\ \qquad\qquad = (a - p_2 + bp_1 + \theta v)(p_2 - c_2) - \dfrac{1}{2}\eta v^2. \end{cases} \tag{2}$$

By solving the first-order partial derivatives of the profit functions, we derive the Nash equilibrium strategies and corresponding profits for the two manufacturers in the benchmark model (2). The results are summarized in Table 3.

The columns p_1 and p_2 denote the equilibrium prices of the FV and EV, respectively. The column v is the EV manufacturer's optimal quality investment level. The columns π_1 and π_2 report the resulting equilibrium profits for the FV and EV manufacturers. In Scenario 2 (S2), the fixed subsidy F appears as an additive term

TABLE 3. The Nash equilibrium solutions under different subsidy scenarios.

Scenarios	p_1	p_2	v
S1	$\frac{(a+bm)\theta^2-(a(b+2)+bm)\eta}{2\theta^2+\left(b^2-4\right)\eta}$	$\frac{2m\left(\theta^2-\eta\right)-a(b+2)\eta}{2\theta^2+\left(b^2-4\right)\eta}$	$\frac{\left(\left(2-b^2\right)m-a(b+2)\right)\theta}{2\theta^2+\left(b^2-4\right)\eta}$
S2	$\frac{(a+bm)\theta^2-(a(b+2)+bm)\eta}{2\theta^2+\left(b^2-4\right)\eta}$	$\frac{2m\left(\theta^2-\eta\right)-a(b+2)\eta}{2\theta^2+\left(b^2-4\right)\eta}$	$\frac{\left(\left(2-b^2\right)m-a(b+2)\right)\theta}{2\theta^2+\left(b^2-4\right)\eta}$
S3	$\frac{a\left(\theta^2-(b+2)\eta\right)-b(m-s)\left(\eta-\theta^2\right)}{2\theta^2+\left(b^2-4\right)\eta}$	$\frac{2(s-m)\left(\eta-\theta^2\right)-a(b+2)\eta}{2\theta^2+\left(b^2-4\right)\eta}$	$\frac{\left(\left(b^2-2\right)(s-m)-a(b+2)\right)\theta}{2\theta^2+\left(b^2-4\right)\eta}$
Scenarios	π_1	π_2	
S1	$\frac{\left(a(b+2)\eta+bm\eta-\left((a+bm)\theta^2\right)\right)^2}{\left(2\theta^2+\left(b^2-4\right)\eta\right)^2}$	$\frac{\left(a(b+2)+\left(b^2-2\right)m\right)^2\eta\left(2\eta-\theta^2\right)}{2\left(2\theta^2+\left(b^2-4\right)\eta\right)^2}$	
S2	$\frac{\left(a(b+2)\eta+bm\eta-\left((a+bm)\theta^2\right)\right)^2}{\left(2\theta^2+\left(b^2-4\right)\eta\right)^2}$	$\frac{\eta\left(2\eta-\theta^2\right)\left(a(b+2)+\left(b^2-2\right)m\right)^2}{2\left(2\theta^2+\left(b^2-4\right)\eta\right)^2}+F$	
S3	$\frac{\left(a(b+2)\eta+b(m-s)\left(\eta-\theta^2\right)-a\theta^2\right)^2}{\left(2\theta^2+\left(b^2-4\right)\eta\right)^2}$	$\frac{\left(a(b+2)+\left(b^2-2\right)(m-s)\right)^2\eta\left(2\eta-\theta^2\right)}{2\left(2\theta^2+\left(b^2-4\right)\eta\right)^2}$	

in π_2 only, confirming that a fixed subsidy does not alter prices or quality investment. In Scenario 3 (S3), the per-unit subsidy s enters through the effective cost term $(m-s)$, shifting both prices and quality investment relative to the no-subsidy benchmark.

Proposition 3.1. *In the benchmark scenario, where the government does not provide subsidies to electric vehicle manufacturers, the Nash equilibrium exists under the following conditions:*

(1) $\frac{\theta^2}{2}<\eta<\frac{2\theta^2}{4-b^2}$, $m>\frac{a(b+2)}{2-b^2}$, *or*
(2) $\frac{2\theta^2}{4-b^2}<\eta\le\theta^2$, $m<\frac{a(b+2)}{2-b^2}$, *or*
(3) $\eta>\theta^2$, $-\frac{a(b+2)\eta}{2(\eta-\theta^2)}<m<\frac{a(b+2)}{2-b^2}$;

Proof. The proof is provided in Appendix A. □

Proposition 3.1 establishes the necessary conditions for the existence of a Nash equilibrium in the benchmark model, where no government subsidies are provided to EV manufacturers. Specifically, the proposition demonstrates how the investment coefficient η, which captures the cost of EV manufacturers' quality-enhancing effort, influences market competition. Depending on the ranges of η and the cost difference m, the equilibrium conditions change, reflecting the interplay between consumer preferences, manufacturing strategies, and market structure.

3.2.2. Scenario 2: Fixed subsidy

When the government provides fixed subsidies to electric vehicle manufacturers, the profit functions for the two automakers can be expressed as follows:

$$\begin{cases} \max\limits_{p_1} \pi_1^{s2} = d_1(p_1-c_1) = (a-p_1+bp_2)(p_1-c_1), \\ \max\limits_{p_2,v} \pi_2^{s2} = d_2(p_2-c_2) - \frac{1}{2}\eta v^2 + F \\ \qquad\qquad = (a-p_2+bp_1+\theta v)(p_2-c_2) - \frac{1}{2}\eta v^2 + F. \end{cases} \tag{3}$$

By solving the first-order partial derivative conditions, we derive the Nash equilibrium strategies and corresponding profits for the two manufacturers in the game model (3). The results are summarized in Table 3.

Proposition 3.2. *In game scenario 2, where the government provides a fixed subsidy to electric vehicle manufacturers, the Nash equilibrium exists under the same conditions as those described in Proposition 3.1.*

Proof. The proof is the same as that of Proposition 3.1, so it is omitted here for brevity. □

Proposition 3.2 establishes the necessary conditions for the game model in which the government provides fixed subsidies to electric vehicle manufacturers, maintaining consistency with the no-subsidy scenario. This consistency indicates a potential relationship between the two game scenarios.

3.2.3. Scenario 3: Quantity subsidy

If the government provides subsidies to electric vehicle manufacturers based on their production quantities, the profit functions of the two automakers can be expressed as follows:

$$\begin{cases} \max\limits_{p_1} \pi_1^{s3} = d_1(p_1 - c_1) = (a - p_1 + bp_2)(p_1 - c_1), \\ \max\limits_{v,p_2} \pi_2^{s3} = d_2(p_2 - c_2) - \dfrac{1}{2}\eta v^2 + sd_2 \\ \qquad\qquad = (a - p_2 + bp_1 + \theta v)(p_2 - c_2 + s) - \dfrac{1}{2}\eta v^2. \end{cases} \tag{4}$$

By solving the first-order partial derivative conditions, we derive the Nash equilibrium strategies and corresponding profits for the two manufacturers in the game model (4). The results are summarized in Table 3.

Proposition 3.3. *In game scenario 3, where the government provides quantity subsidies to electric vehicle manufacturers, the Nash equilibrium solution exists under the following conditions:*

(1) $\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$, $m > s + \frac{a(b+2)}{2-b^2}$, *or*
(2) $\frac{2\theta^2}{4-b^2} < \eta \leq \theta^2$, $m < s + \frac{a(b+2)}{2-b^2}$, *or*
(3) $\eta > \theta^2$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < s + \frac{a(b+2)}{2-b^2}$.

Proof. The proof is similar to Proposition 3.1, so it is omitted here for brevity. □

Proposition 3.3 establishes the necessary conditions for the existence of a Nash equilibrium when the government implements quantity subsidies for EV manufacturers. Compared to the previous two game scenarios, the effects of production cost differences m and subsidy intensity s are significantly different. This finding highlights the importance of considering the cost differences between the production of FVs and EVs in future research, as these differences significantly influence the outcomes of subsidy policies.

3.2.4. Unified constraint conditions

To facilitate a more effective comparison of these three game scenarios, the following corollary is derived from Propositions 3.1–3.3. This corollary establishes a unified domain of definition for the analysis and comparison of the three subsidy scenarios.

Corollary 3.4. *The definition domain for the three game scenarios can be summarized as follows:*

Case 1: $\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$, $m > s + \frac{a(b+2)}{2-b^2}$, *or*
Case 2: $\frac{2\theta^2}{4-b^2} < \eta \leq \theta^2$, $m < \frac{a(b+2)}{2-b^2}$, *or*
Case 3: $\eta > \theta^2$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$.

Proof. The proof is provided in Appendix B. □

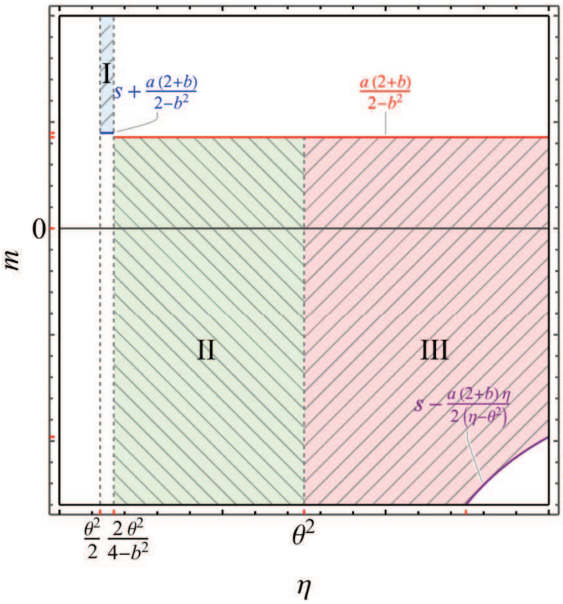


FIGURE 3. The unified domain of definition.

To provide an intuitive understanding of the parameter space within the defined domain, Figure 3 illustrates the feasible region in the (η, m) plane. The parameter space is divided into several regions: Region I corresponds to Case 1 in the Corollary 3.4, Region II corresponds to Case 2 in the Corollary 3.4, and Region III corresponds to Case 3 in the Corollary 3.4. As shown in the figure, the parameter m can have both positive and negative values, reflecting the differences in manufacturing costs between EVs and FVs. In this study, we focus on the range where $m > 0$ due to the EVs' relatively higher manufacturing costs. However, with ongoing technological advancements, the production costs of EVs may fall below those of FVs, and more complex scenarios that require further investigation.

Based on Corollary 3.4, the following section compares the effects of the three game scenarios on prices, quality investment, and profits under the feasibility conditions.

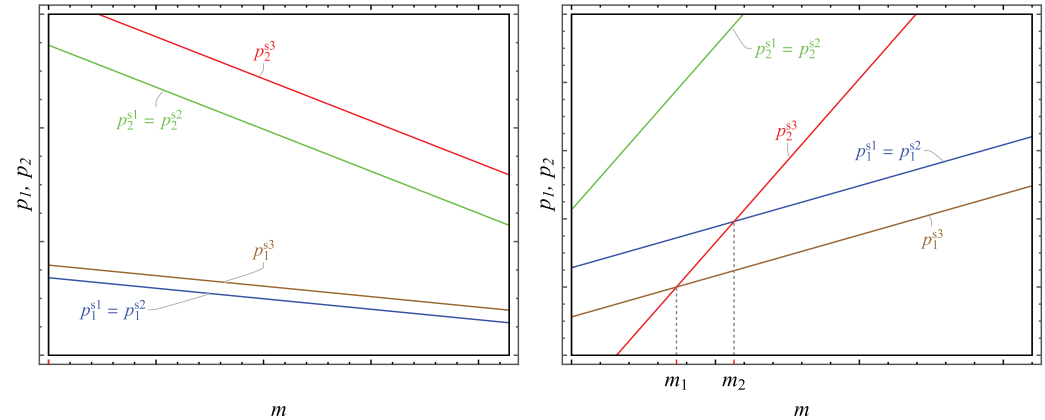
In this study, we exclude Case 1 from the main discussion. A low investment coefficient means that firms can improve quality at a lower marginal cost. In practice, this may reflect a more mature technological environment. The model suggests that quantity subsidies have only a limited effect on equilibrium outcomes. As a result, strong policy intervention is less necessary. A detailed analysis of Case 1 is provided in Appendix D. As technology becomes mature, the effect of subsidies may decline. In our model, the more policy relevant cases are those with moderate or high investment coefficients, where subsidies have a stronger effect on firms' decisions.

4. Model comparison and analysis

In this section, we compare these equilibria to investigate the complex relationships and dynamic effects that emerge under different subsidy scenarios. Proposition 4.1 compares FV and EV prices across the three game scenarios and shows how the investment coefficient and production cost differences affect equilibrium pricing.

Proposition 4.1. *The optimal prices p_1 and p_2 across the three game scenarios satisfy the following relationships:*

(1) $p_1^{s1} = p_1^{s2} < p_1^{s3}$ *and* $p_2^{s1} = p_2^{s2} < p_2^{s3}$ *hold, when*
$-\frac{2\theta^2}{4-b^2} < \eta < \theta^2$, $m < \frac{a(b+2)}{2-b^2}$;



(a) $\frac{2\theta^2}{4-b^2} < \eta \leq \theta^2$ (b) $\eta > \theta^2$

FIGURE 4. Equilibrium prices p_1 and p_2 across the three subsidy scenarios.

(2) $p_1^{s3} < p_1^{s1} = p_1^{s2}$ *and* $p_2^{s3} < p_2^{s1} = p_2^{s2}$ *hold, when*
– $\eta > \theta^2$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$.

Proof. The proof is provided in Appendix C. □

Proposition 4.1 shows that fixed subsidies do not change vehicle prices. However, in a quantity subsidy scenario, prices may change with the investment coefficient and differences in production costs. When the investment coefficient is high, both EV and FV prices decrease. While it makes sense for EV prices to drop with subsidies, FV prices are also explained due to competitive pricing strategies, such as price wars, where manufacturers reduce prices to stay competitive.

When the investment coefficient is moderate, quantity subsidies may cause higher prices, which is unfavorable for consumers to choose affordable, high-quality products. Policymakers must carefully consider this phenomenon to avoid market imbalance. Although Proposition 4.1 explores how subsidy policies influence pricing strategies, manufacturers often profitability. Therefore, we will explore the effects of different subsidy policies on manufacturers' profits, providing policymakers with more practical guidance.

Figure 4 shows that when the investment coefficient is moderate (see Fig. 4a), subsidies have no impact in game scenarios 1 and 2. The blue solid line represents the price of FVs, while the green solid line represents the price of EVs. Furthermore, the price of EVs is higher than that of FVs, reflecting real-world conditions in which high battery costs push up EV prices. To address this issue, governments often implement subsidy programs to promote EV adoption.

However, under the subsidy strategy, although both prices of FVs and EVs increase, the price of FVs remains lower than that of EVs. It indicates that the subsidy changes equilibrium prices and strengthens the EV manufacturer's competition.

When the investment coefficient is relatively large (see Fig. 4b), the relationships become complex. In scenarios 1 and 2, the price of EVs remains higher than that of FVs. In Figure 4b, m_1 and m_2 denote the cost difference thresholds at which the price curves under different subsidy scenarios. However, with the introduction of a subsidy policy, the prices decrease for both types of vehicles. Specifically, when the production cost difference between FVs and EVs satisfies $m < m_1$, the price of EVs in scenario 3 is the lowest. as m increases, the price of EVs gradually rises. When $m_1 < m < m_2$, the price of EVs remains lower than scenarios 1, yet higher than the price of FVs. When the cost difference becomes large ($m > m_2$), the price of EVs increases but remains

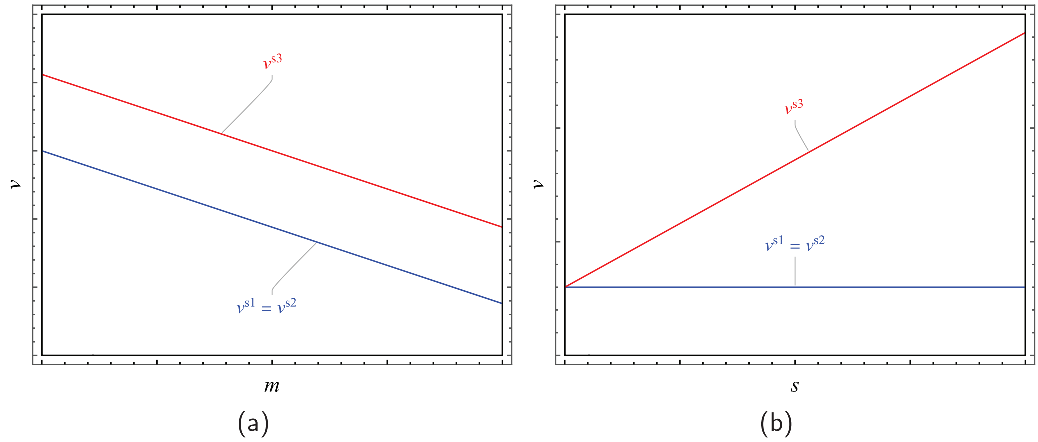


FIGURE 5. Equilibrium quality investment v across the three subsidy scenarios.

lower than in other scenarios. It highlights that well-designed subsidy policies can guide market competition and support the transition to sustainable industries.

It is also useful to examine how equilibrium prices respond to key parameters. A higher consumer preference coefficient θ means that consumers place more weight on quality differences. Under quantity subsidies, this increases the equilibrium prices of both manufacturers. By contrast, a higher price sensitivity coefficient b makes the two products closer substitutes. As a result, the feasibility conditions in Corollary 3.4 become harder to satisfy. Therefore, the results are more relevant to markets where EVs and FVs remain sufficiently differentiated.

Proposition 4.1 only demonstrates the impact of policies on price; the following Proposition 4.2 further presents the changes in quality investment.

Proposition 4.2. *The optimal quality investment v for manufacturer M_2 across the three game scenarios satisfies $v^{\mathrm{s1}} = v^{\mathrm{s2}} < v^{\mathrm{s3}}$, when*

– $\frac{2\theta^2}{4-b^2} < \eta \le \theta^2$, $m < \frac{a(b+2)}{2-b^2}$, *or*
– $\eta > \theta^2$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$.

Proof. The proof is similar to Proposition 4.1, so it is omitted here for brevity. □

Proposition 4.2 shows that the EV manufacturer's quality investment v increases under the quantity subsidy scenario. When the investment coefficient η is moderate or large, quantity subsidies raise the equilibrium level of quality-enhancing effort. Although the cost difference m affects this result, its role here is to measure the EV–FV cost differential rather than firms' financial resources. The result therefore suggests that quantity subsidies are more effective when the EV cost disadvantage remains within a moderate range.

Furthermore, Figure 5a illustrates these relationships in Proposition 4.2 through the blue and red lines. The quantity subsidy policy, in particular, leads to higher quality investment, which benefits consumers by improving EV attributes and strengthening perceived. It demonstrates that government subsidies can provide direct incentives for quality enhancing effort. Additionally, Figure 5b highlights this positive relationship from the perspective of subsidy intensity (s). As subsidy intensity increases, EV quality investment rises. Counterintuitively, the

A higher θ strengthens the EV manufacturer's incentive to invest, translating into higher equilibrium v, p_2, and π_2 under Scenario 3. As shown in Figure 5b, a higher subsidy intensity s monotonically raises v^{ds3} and p_2^{s3}. Conversely, a higher investment cost coefficient η raises the marginal cost of quality investment, reducing v and weakening the effectiveness of quantity subsidies. When η is low (Case 1 of Cor. 3.4), subsidies are inefficient

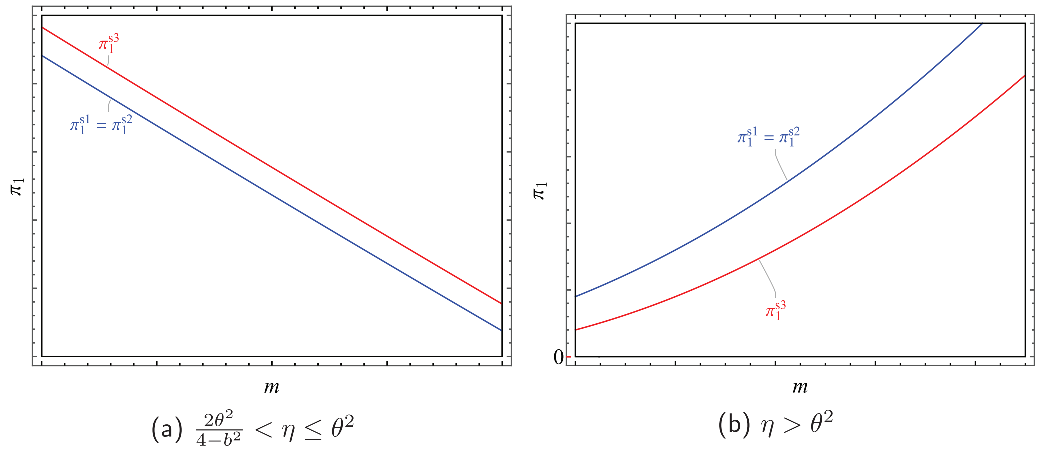


FIGURE 6. Equilibrium profits π_1 of the FV manufacturer across the three subsidy scenarios.

regardless of type, as shown in Appendix D. The most favorable outcomes arise in the moderate-to-high η range (Cases 2 and 3), where investment costs are non-trivial but not prohibitive.

The purpose of government subsidy policies is to promote the development of the EV industry, benefiting both consumers and manufacturers. From the perspective of businesses, the primary objective is to achieve higher profits. Propositions 4.3 and 4.4 analyze the changes in profitability under different strategies for FV manufacturers and EV manufacturers, respectively.

Proposition 4.3. *The optimal profits π_1 for manufacturer M_1 across the three game scenarios satisfy the following relationships:*

(1) $\pi_1^{s1} = \pi_1^{s2} < \pi_1^{s3}$ *holds, when*
- $\frac{2\theta^2}{4-b^2} < \eta \leq \theta^2$, $m < \frac{a(b+2)}{2-b^2}$,

(2) $\pi_1^{s3} < \pi_1^{s1} = \pi_1^{s2}$ *holds, when*
- $\eta > \theta^2$, $0 < s < \frac{a(b+2)}{2-b^2} + \frac{a(b+2)\eta}{2(\eta-\theta^2)}$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$,

Proof. The proof is similar to Proposition 4.1, so it is omitted here for brevity. □

Proposition 4.4. *The following relationships hold for the profits π_2 of manufacturer M_2 across the three subsidy scenarios:*

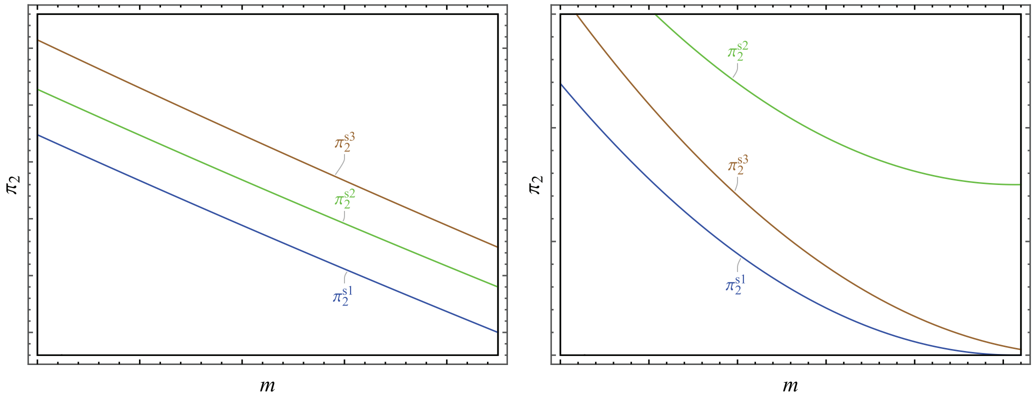
(1) $\pi_2^{s1} < \pi_2^{s2} < \pi_2^{s3}$ *holds, when*
- $\frac{2\theta^2}{4-b^2} < \eta < \theta^2$, $m < \frac{a(b+2)}{2-b^2}$, $F < F_1$, *or*
- $\eta > \theta^2$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$, $F < F_1$;

(2) $\pi_2^{s1} < \pi_2^{s3} < \pi_2^{s2}$ *holds, when*
- $\frac{2\theta^2}{4-b^2} < \eta < \theta^2$, $m < \frac{a(b+2)}{2-b^2}$, $F > F_1$, *or*
- $\eta > \theta^2$, $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$, $F > F_1$;

where $F_1 = \frac{(2-b^2)\eta s(2\eta-\theta^2)(2a(b+2)-(2-b^2)(2m-s))}{2((b^2-4)\eta+2\theta^2)^2}$.

Proof. The proof is similar to Proposition 4.1, so it is omitted here for brevity. □

Proposition 4.3 presents the profit patterns of FV manufacturers across different scenarios. It indicates that profits remain unchanged in both the no-subsidy scenario and the fixed-subsidy scenario. However, under a



(a) $F < F_1$ (b) $F > F_1$

FIGURE 7. Equilibrium profits π_2 of the EV manufacturer across the three subsidy scenarios.

quantity subsidy policy, profits increase significantly when the investment coefficient is moderate. Conversely, when the investment coefficient is high, quantity subsidies reduce FV manufacturer profits, as the high marginal cost of quality investment limits the technological improvement that subsidies can induce, while the resulting competitive pressure still erodes FV manufacturers' market position.

Proposition 4.4 points out that in a no-subsidy scenario, the profits of EV manufacturers are at their lowest across all three scenarios. Under subsidy policies, if the fixed subsidy $F < F_1$, a quantity subsidy strategy results in the highest profits for EV manufacturers, while fixed subsidies yield moderate profits. Conversely, when the fixed subsidy $F > F_1$, the quantity subsidy strategy leads to lower profits compared to the fixed subsidy strategy. This is primarily because the total subsidy amount under the quantity approach is less than that of the fixed subsidy, allowing manufacturers to benefit more significantly from the larger financial support provided by the government.

When the fixed subsidy exceeds the threshold, the advantage of quantity subsidies becomes smaller. In addition, the profitability of FV manufacturers under quantity subsidies depends on the investment coefficient. For moderate values of η, quantity subsidies raise FV profits, whereas for high values of η, they reduce FV profits because the competitive pressure generated by subsidized EVs dominates the market expansion effect.

Figures 6 and 7 illustrate how profits change with the key parameters under different subsidy scenarios, and visually validate the theoretical analysis and further reveal trends under different strategies.

The sensitivity of profits to parameter changes shows several important trade-offs in subsidy design. A higher θ increases π_2 under Scenario 3, but it also increases pressure on the FV manufacturer and reduces π_1. A higher s increases π_2^{s3}, but reduces π_1^{s3} when $\eta > \theta^2$. It means that the subsidy rate should be set carefully, so that it does not place excessive pressure on FV manufacturers.

5. Conclusion and policy implications

This study examines how fixed and quantity subsidies affect price competition, quality investment, and firm profits in a market with EV and FV manufacturers. The results show that fixed subsidies do not change equilibrium prices or quality investment, but mainly act as transfers to the EV manufacturer. Quantity subsidies have a stronger incentive effect. They can promote quality investment and improve market outcomes when the subsidy rate is properly set. However, the effectiveness of both policies depends on the cost difference, and subsidies work better when this cost gap remains within a moderate range.

First, subsidies are less necessary when the investment coefficient is low. In this case, additional public support does not improve product quality and may even reduce the profits of both firms. Therefore, subsidy programs should focus on settings where further investment can still raise product quality.

Second, fixed subsidies have a limited strategic role. They can ease financial pressure on EV manufacturers, especially in early-stage markets, but they have little effect on pricing, quality investment, or market competition.

Third, quantity subsidies are more flexible, but they need careful design. A higher s can strengthen EV quality investment and competitiveness, but it may also increase pressure on FV manufacturers. Therefore, quantity subsidies should be set according to the parameter conditions and gradually reduced as the EV cost disadvantage narrows.

This study also has several limitations. This model framework is static and single-period, so it does not capture dynamic subsidy adjustment, learning effects, or intertemporal strategies. Future research could consider different supply chain structures or interactions between subsidies and other policy tools, such as carbon pricing, carbon taxes, and technology mandates. Empirical and numerical analysis would also help connect the theoretical results with policy practice.

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Conflicts of interest

The authors declare no potential conflicts of interest.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

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Appendix A. Proofs of Proposition 3.1

Proof. We first use the profit function of manufacturer M_2 to derive the concavity condition for the EV manufacturer's optimization problem. The Hessian matrix with respect to (p_2, v) is $H = \begin{pmatrix} -2 & \theta \\ \theta & -\eta \end{pmatrix}$, where $-2 < 0$ always holds. Negative definiteness therefore requires $\det H = 2\eta - \theta^2 > 0$, which implies $\eta > \frac{\theta^2}{2}$. This is the basic feasibility condition used in the sign analysis below. Furthermore, the decision variables p_1, p_2, and v must be positive, and the profits π_1 and π_2 must also be positive. We take $p_1 > 0$ as an example. Let $D = 2\theta^2 + \left(b^2 - 4\right)\eta$ and $N_1 = \theta^2(a + bm) - \eta(a(b+2) + bm) = a\left(\theta^2 - \eta(b+2)\right) + bm\left(\theta^2 - \eta\right)$.

Then $p_1 = \frac{N_1}{D}$. Hence, $p_1 > 0$ holds if and only if N_1 and D have the same sign, that is, either $N_1 > 0$ and $D > 0$, or $N_1 < 0$ and $D < 0$.

Since $b \in [0, 1]$, we have $b^2 - 4 < 0$. Therefore, $D > 0$ is equivalent to $\eta < \frac{2\theta^2}{4-b^2}$, whereas $D < 0$ is equivalent to $\eta > \frac{2\theta^2}{4-b^2}$.

We now consider the three cases in Proposition 3.1.

Case 1: If $\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$, then $D > 0$. In this region, we also have $\eta < \theta^2$, so N_1 is increasing in m. Evaluating N_1 at $m = \frac{a(b+2)}{2-b^2}$ gives $N_1 = \frac{a(b+1)\left(2\theta^2 + \left(b^2-4\right)\eta\right)}{2-b^2} > 0$.

Hence, when $m > \frac{a(b+2)}{2-b^2}$, we have $N_1 > 0$. Since also $D > 0$, it follows that $p_1 > 0$.

Case 2: If $\frac{2\theta^2}{4-b^2} < \eta \leq \theta^2$, then $D < 0$. In this region, N_1 is still increasing in m. Evaluating again at $m = \frac{a(b+2)}{2-b^2}$, we obtain

$N_1 = \frac{a(b+1)\left(2\theta^2+\left(b^2-4\right)\eta\right)}{2-b^2} < 0.$

Therefore, for $m < \frac{a(b+2)}{2-b^2}$, we have $N_1 < 0$. In this case, both the numerator and denominator are negative, so $p_1 > 0$ also holds.

Case 3: If $\eta > \theta^2$, then $D < 0$ and N_1 is decreasing in m. Evaluating N_1 at $m = -\frac{a(b+2)\eta}{2\left(\eta-\theta^2\right)}$ yields $N_1 = \frac{a}{2}\left(2\theta^2 + \left(b^2-4\right)\eta\right) < 0$.

Thus, for $m > -\frac{a(b+2)\eta}{2\left(\eta-\theta^2\right)}$, we have $N_1 < 0$. Combined with the upper bound $m < \frac{a(b+2)}{2-b^2}$, both the numerator and denominator remain negative, and therefore $p_1 > 0$.

The positivity conditions for p_2, v, π_1, and π_2 can be verified analogously, which completes the proof of Proposition 3.1. □

Appendix B. Proofs of Corollary 3.4

Proof. From the first set of conditions, when $\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$, we have $m > \frac{a(b+2)}{2-b^2}$ (in Props. 3.1 and 3.2), and $m > s + \frac{a(b+2)}{2-b^2}$ (in Prop. 3.3).

For these two conditions, the stricter lower bound will dominate. Since $m > s + \frac{a(b+2)}{2-b^2}$ is always greater than or equal to$m > \frac{a(b+2)}{2-b^2}$ (assuming $s > 0$), the intersection for this range is $m > s + \frac{a(b+2)}{2-b^2}$.

From the first set of conditions, when $\frac{2\theta^2}{4-b^2} < \eta \leq \theta^2$, we have $m < \frac{a(b+2)}{2-b^2}$ (in Props. 3.1 and 3.2), and $m < s + \frac{a(b+2)}{2-b^2}$ (in Prop. 3.3).

For these two conditions, the stricter upper bound will dominate. Since $m < \frac{a(b+2)}{2-b^2}$ is always less than or equal to$m < s + \frac{a(b+2)}{2-b^2}$ (assuming $s > 0$), the intersection for this range is $m < \frac{a(b+2)}{2-b^2}$.

From the first set of conditions, when $\eta > \theta^2$, we have $-\frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$ (in Props. 3.1 and 3.2), and$s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < s + \frac{a(b+2)}{2-b^2}$ (in Prop. 3.3).

For the lower bound, the stricter condition is given by:

$$\max\left(-\frac{a(b+2)\eta}{2(\eta-\theta^2)}, s - \frac{a(b+2)\eta}{2(\eta-\theta^2)}\right) = s - \frac{a(b+2)\eta}{2(\eta-\theta^2)},$$

since $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)}$ is always greater than or equal to$-\frac{a(b+2)\eta}{2(\eta-\theta^2)}$ (assuming $s > 0$).

For the upper bound, the stricter condition is given by:

$$\min\left(\frac{a(b+2)}{2-b^2}, s + \frac{a(b+2)}{2-b^2}\right) = \frac{a(b+2)}{2-b^2},$$

since $\frac{a(b+2)}{2-b^2}$ is always less than or equal to$s + \frac{a(b+2)}{2-b^2}$ (assuming $s > 0$).

Thus, the proof is complete. □

Appendix C. Proofs of Proposition 4.1

Proof. Obviously, $p_1^{s1} = p_1^{s2}$.

Similarly, $p_2^{s1} = p_2^{s2}$.

Let

$$\Delta_1 = p_1^{s3} - p_1^{s1} = \frac{bs\left(\eta-\theta^2\right)}{(b^2-4)\eta + 2\theta^2}$$

and

$$\Delta_2 = p_2^{s3} - p_2^{s1} = \frac{2s\left(\eta-\theta^2\right)}{(b^2-4)\eta + 2\theta^2}.$$

Since we are ignoring the low investment coefficient case (*i.e.*, $\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$), we focus on two scenarios:

(1) For $\frac{2\theta^2}{4-b^2} < \eta < \theta^2$ and $m < \frac{a(b+2)}{2-b^2}$.

In this case, $\left(b^2-4\right)\eta + 2\theta^2 < 0$ and $\eta - \theta^2 < 0$. Since $b > 0$ and $s > 0$, we have $\Delta_1 > 0$ and $\Delta_2 > 0$. Therefore, $p_1^{s1} = p_1^{s2} < p_1^{s3}$ and $p_2^{s1} = p_2^{s2} < p_2^{s3}$.

(2) For $\eta > \theta^2$ and $s - \frac{a(b+2)\eta}{2(\eta-\theta^2)} < m < \frac{a(b+2)}{2-b^2}$.

In this case, $\left(b^2-4\right)\eta + 2\theta^2 < 0$ and $\eta - \theta^2 > 0$. Since $b > 0$ and $s > 0$, we have $\Delta_1 < 0$ and $\Delta_2 < 0$. Therefore, $p_1^{s3} < p_1^{s1} = p_1^{s2}$ and $p_2^{s3} < p_2^{s1} = p_2^{s2}$.

Thus, the proof is complete. □

Appendix D. Low investment coefficient ($\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$)

The following Proposition D.1 presents the relationship between the decision variables of fuel vehicle manufacturers and electric vehicle manufacturers, as well as their respective payoffs, under the condition of a low investment coefficient ($\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$). This analysis highlights how the level of investment affects the strategic choices and resulting profits of both types of manufacturers within the specified range of η.

Proposition D.1. *When the investment coefficient is low, $\frac{\theta^2}{2} < \eta < \frac{2\theta^2}{4-b^2}$, and $m > s + \frac{a(b+2)}{2-b^2}$, the following relationships emerge across the three game scenarios.*

(1) $p_1^{s3} < p_1^{s1} = p_1^{s2}$;
(2) $p_2^{s3} < p_2^{s1} = p_2^{s2}$;
(3) $v^{s3} < v^{s1} = v^{s2}$;
(4) $\pi_1^{s3} < \pi_1^{s1} = \pi_1^{s2}$;
(5) $\pi_2^{s3} < \pi_2^{s1} < \pi_2^{s2}$.

Proof. The proof is similar to Proposition 4.1, so it is omitted here for brevity. □

The analysis of Proposition D.1 shows that in game scenario 3, quantity subsidies consistently lead to the lowest prices, quality investment, and payoffs for both fuel vehicle and electric vehicle manufacturers. While the lower prices may initially appear advantageous for consumers, the simultaneous decline in quality investment suggests that these subsidies are unlikely to encourage long-term adoption or continued use of EVs through sustained quality improvement.

Additionally, the decreased profits for both types of manufacturers indicate that these subsidies fail to provide sufficient incentives for innovation or market growth. For manufacturers, this lack of motivation restricts their capacity to invest in product improvement or cost reduction. From the government's perspective, such subsidies represent an inefficient allocation of resources, as they do not achieve key objectives such as promoting technological advancement or fostering sustainable industry growth.

Therefore, this study recommends that governments stop subsidies based on sales quantities under these conditions. Instead, reallocating resources to more effective policy tools could better support market development and technological innovation.