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Tripartite Coordinated Regulation of New Energy Vehicles Based on Dynamic Bayesian Game

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Manufacturers are disseminating false or ambiguous information regarding new energy vehicles (NEVs), which has led to skepticism from consumers about the quality of NEVs. In this research, we simultaneously considered the relationship among manufacturers, consumers, and governments from the perspective of stakeholders, and then we analyzed the tripartite coordinated regulation. In view of the serious information asymmetry of NEVs, we innovatively developed the Bayesian dynamic game model. By solving refined Bayesian equilibrium strategies, this study explores the effects of key influencing factors on strategic choices. On the basis of the conclusion, relevant countermeasures and suggestions are put forward to engender effective regulation by governments.

Keywords: new energy vehicles, coordinated regulation, tripartite game, Bayesian game model, environmental policy

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INTRODUCTION

Environmental deterioration issues such as high emission levels and global warming have become a global focus during the past decades. Energy-saving products (ESPs) with the features of carbon emission reduction and low-energy consumption are key measures to solve pollution emissions and resource depletion (Yu et al., 2019; Ji et al., 2020). There are many ESPs, such as energy-saving automobiles, air conditioners, water dispensers, and so on. In this paper, we choose typical new energy vehicles (NEVs) as representative products. With the support of governmental policies, the NEV market scale continues to expand. However, the misuse of eco-labels and fake products has become more widespread. This has caused a series of defrauding incidents (Chen and Chang, 2013; Guyader et al., 2017). For example, in 2015, regulators from the United States confirmed that the German automaker Volkswagen had installed fake equipment that allowed the vehicles to pass emissions tests. However, in reality, the vehicles emitted up to 40 times the acceptable levels of harmful gasses and nitrogen oxides. In 2016, the Chinese government conducted a special inspection of NEVs and revealed that the production of 76,000 NEVs was associated with fraud, including five major manufacturers, such as Suzhou Jimsey Bus Manufacturing Co., Ltd.

Many researchers have indicated that consumers are willing to pay higher prices for NEVs, which encourages manufacturers to produce them (Liu et al., 2012; Chander and Muthukrishnan, 2015). However, dishonest manufacturers have caused poor purchasing decisions for consumers as well as a loss of credibility for NEVs. Despite the tighter regulations in place to stop speculations, including legislation and financial instruments, the results reveal that regulations in NEVs do not effectively reduce the incidence of fake and inferior behaviors (Zhao et al., 2020). Thus, solving how to reduce the increasingly severe deception problem and ensure the quality of NEVs is an urgent concern. Considering these practical problems, the relevant regulation policies need to be developed urgently.

Consumers are important stakeholders, who not only affect the environmental performance of manufacturers but also influence the efficiency of regulation (Hammami et al., 2018; Yang et al., 2020). However, the current research mainly pays close attention to discussing how manufacturers respond to government policies. In particular, the role of consumers was relatively limited and concentrated on in previous studies. Studies on multi-agent relationships and collaborative regulation mechanisms have remained scarce. Therefore, excluding manufacturers and governments and adding consumers as stakeholders in the game can help further explore the regulation of NEVs. Therefore, tripartite coordinated regulation of NEVs represents more realistic situations, and the interaction relationship among the three participants can also be analyzed.

Stakeholders involve multiple members who may not want to share private information, especially manufacturers whose product quality is faked. With regard to the quality of NEVs, serious information asymmetry is also an important factor that cannot be ignored (Zhang et al., 2019; Wang Y. et al., 2020). The assumption in the previous game that participants in NEVs provide complete information is too idealistic (Shen et al., 2019). To the best of our knowledge, no NEV studies have taken asymmetry information and tripartite game into consideration simultaneously.

In this paper, we take manufacturers, consumers, and governments into account concurrently. We study the tripartite coordinated regulation of NEVs under the condition of asymmetric information. Several questions are of interest:

1. What are the game relationships among governments, manufacturers, and consumers?
2. With the asymmetric information, how can the tripartite game model among governments, manufacturers, and consumers in NEVs be formulated?
3. What are the key influencing factors affecting the different participants in the equilibrium strategy?

The motivations of our research for solving the above problems are the following: (1) This paper proposes a Bayesian game model, which differs from the previous perfect information game, to analyze the decisions of government regulation, consumers' consumption, and manufacturer production in asymmetric information. (2) Discuss the tripartite coordinated regulation on the quality of NEVs to investigate the decisions of different participants and obtain the optimal strategy. (3) Analyze the interplay and key factors affecting the choices of game players. Targeted regulatory measures will also be proposed.

The remainder of this paper is organized as follows. In section 2, the relevant literature is reviewed. In section 3, we provide our problem assumptions and basic model, and derive the utility functions of the game players. In section 4, we present and analyze the equilibrium possibility. Finally, in section 5, we summarize our concluding remarks and discuss directions for future research.

LITERATURE REVIEW

The literature is related to various research aspects on environmental regulation. Our literature review primarily relates to three research streams: the effects of environmental regulation on manufacturers, the behavior strategy selection of stakeholders, and the differential game models in ESPs. Key studies from the different research streams are reviewed briefly in the following subsections.

Effects of Environmental Regulation on Manufacturers

As more and more regulations on environmental protection are issued in practice, extensive literature on the effects of different types of regulation on manufacturers, such as carbon taxes, subsidies, and cap and trade, has emerged (Zhou and Huang, 2016; Liao and Shi, 2018).

Many scholars have discussed that government intervention and policies are critical to the environmental performance of manufacturers. Hafezi and Zolfagharinia (2018) proposed that governments should impose regulations with caution as firms may opt for a strategy that provides a larger profit at the expense of total environmental performance. Hafezalkotob (2015) developed a competition model of two green and regular supply chains under environmental protection and revenue seeking policies of government. Peng et al. (2019) investigated the main causes of environmental regulation failure and found that governments should strengthen regulations from the aspects of improving laws, establishing a monitoring system, and innovating incentive and constraint mechanisms. Murali et al. (2019) developed a framework for studying the impact of voluntary eco-labels and mandatory environmental regulation on green product development among competing firms.

Most studies from the perspective of governments have been performed on the policy of regulation and analyzing whether the tools and mechanisms effectively influence the decisions of manufacturers. Even though Gouda et al. (2016) addressed a manufacturer's product quality choice problem and proposed a composite regulatory solution, the study only discussed traditional and environmental qualities. However, the especially for manufacturers to fraud have rarely been analyzed. Ensuring that the quality of NEVs meets the requirements is the premise of developing them. Hence, when considering the incidence of fake and inferior behaviors, it is necessary to examine how to achieve effective regulation policy in its game with both manufacturers and governments.

Behavior Strategy Selection of Stakeholders

The behavior strategy selection of stakeholders is becoming increasingly prominent in research (Geng et al., 2021). Thus far, the literature is rich on green supply chains and renewable energy development in terms of different stakeholders (Xu X. F. et al., 2019). Considering the manufacturers and retailers,

TABLE 1 | Papers most related to our research.

Authors	Energy-saving products	Government regulation	Asymmetric information	Tripartite game
Rocha and Salomao (2019)		✓		
Zhang et al. (2020)	✓	✓		
Zhao et al. (2020)	✓	✓		
Sun and Zhang (2019)		✓	✓	
Yang et al. (2018)			✓	✓
Feng et al. (2019)	✓	✓		
Deng et al. (2013)			✓	✓
This paper	✓	✓	✓	✓

The symbol ✓ indicates that paper has the corresponding topic.

Zhang et al. (2020) analyzed the optimal decisions of a green supply chain and revealed the impacted difference between manufacturer and retailer behavior on equilibrium solutions in the context of a government subsidy. Deng et al. (2013) proposed a principal-agent model to study a supply chain consisting of a manufacturer and a retailer with asymmetric information. Zhou et al. (2018) discussed a cooperative advertising and ordering issue in a two-echelon supply chain in which a risk-averse manufacturer sells a product through a risk-averse retailer. Choi et al. (2018) and Wang et al. (2019) explored how the stochastic risk preference of retailers affects the values of quick response to the supply chain and its members. Feng et al. (2019) formalized the game's theoretic model of manufacturers associated with governments in a low-carbon technology market and derived the mixed strategy Nash equilibrium. Ye et al. (2019) introduced the environmental governance cost prediction and showed that different risk coefficients have a greater impact on the investment in environmental governance. Liao et al. (2020) analyzed the effects of behavioral intention on the choice to purchase energy-saving appliances in China and revealed that behavioral intention has a significantly positive effect on the choice of consumers.

The literature mentioned above mainly indicates that behaviors between governments and manufacturers have been widely discussed. The role of consumers and their environmental awareness are also investigated as critical factors for manufacturers to promote ESPs (Li and Li, 2016; Liao and Shi, 2018). Very little research has looked at the impact of consumers' behavior on NEVs when governments provide regulations for manufacturers. In particular, the incorporating role of synergistic regulatory effects should be discussed in depth. This study takes the perspective of associated production, consumption, and regulation in considering the whole process of NEVs. This could have a great impact on the efficiency of environmental regulation.

Differential Game Models in ESPs

Game theory provides a powerful tool with which to unpack the interactive strategies of governments and manufacturers, focusing particularly on the conflict of interests between them under environmental regulation. Assuming the participant is completely rational, Zu et al. (2018) used a Stackelberg differential game with three progressive environmental regulation situations to consider a two-echelon supply chain consisting of one manufacturer and one supplier that tries to increase sustainable profits by making efforts to reduce CO_2 emission. Zhao et al. (2020) constructed a perfect game model including the subsidy policies of governments, manufacturers, and customers. During their study, the crucial influencing factors of the governments' and manufacturers' strategies were discussed. Zhou and Huang (2016) modeled a three-stage game and presented an optimal design of the contracts under government regulation for ESPs.

Recently, on the basis of the bounded rationality hypothesis, evolutionary game theory has been widely used on new energy products (Yu et al., 2020). Jiang et al. (2019) implemented a multi-agent environmental regulation strategy under Chinese fiscal decentralization by using an evolutionary game theoretical approach. Xing et al. (2017) constructed an evolutionary game of environmental regulation among local governments in China and analyzed the dynamic evolution rules of the environmental regulation strategy. Sun and Zhang (2019) divided enterprises into two types, dominant and inferior, and analyzed the evolutionarily stable strategy of heterogeneous enterprises in preventing greenwashing. Rocha and Salomao (2019) presented an evolutionary game to study the interaction between polluting firms and auditors. For a tripartite game model, Duan et al. (2016) developed two systems of dynamics-based tripartite evolutionary game models: a government environmental regulation-static punishment model and a dynamic punishment model. Liu and Xia (2020) analyzed the strategies of governments, manufacturers, and consumers according to the evolutionary game model in new energy products.

Most game models assume that information is symmetric and are mainly for two-player games, such as non-cooperative, cooperative and evolutionary game. As far as we know, few works have studied the strategy choices of tripartite coordinated regulation for NEVs with incomplete information. The manufacturer has private information about product quality, and the governments and consumers can only observe the quality level of the products posteriori. Therefore, tripartite dynamic game relationships should be discussed to explore the predicament and countermeasures of governance (Wang D. L. et al., 2020). A Bayesian game is an efficient way to solve the incomplete information game problem and is a more reasonable means to describe the strategies chosen by participants in NEVs (Yang et al., 2018). Therefore, this study attempts to explore the impacts of the interactions of governments, manufacturers, and consumers via the Bayesian game.

To highlight the innovation of this study and clearly show its difference from previous literature, we summarize the literature most related to our paper in **Table 1**.

PROBLEM ASSUMPTIONS AND MODEL DEVELOPMENT

The game model of product quality regulation involves three participants: governments, manufacturers, and consumers. The relationships among NEVs stakeholders is shown in **Figure 1**.

Manufacturers are responsible for the production, quality, and sale of NEVs, and governments design regulation standards to motivate manufacturers to improve their quality and protect consumers.

Problem Assumptions

Considering the reality of NEVs, such as the tripartite dynamic game model presented by Yang et al. (2019) and Xu et al. (2020), incorporating the characteristics of NEVs and regulation policies, research assumptions are proposed to conduct a better analysis of the game problem in decision-making behaviors. Additionally, the parameters involved in the models are accurately defined.

Assumption 1. We introduce "Nature," which is considered under different product qualities, and with the products divided into two types $i (i = H, L)$. The strategy set of nature is high-quality products and low-quality products. This is consistent with the literature, such as Cai et al. (2019). So, we only consider two types of products in the market. High-quality products refer to products that adopt energy-saving technology and meet the emission standards set by governments. For NEVs, governments propose standards that mainly include energy consumption over 100 km and emissions. Of course, manufacturers can also implement higher standards to improve product quality. The probability that manufacturers design high-quality products is $P(i = H) = \theta, \theta \in [0, 1]$. From the perspective of quality standards formulated by the government, only unqualified product standards are considered low-quality products. Thus, the probability is denoted by $P(i = L) = 1 - \theta$. The quality of NEVs is private information.

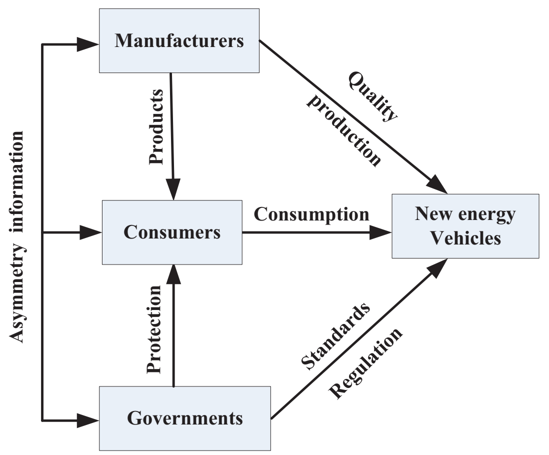

FIGURE 1 | Relationship among stakeholders in NEVs.

TABLE 2 | Parameters and implications.

For governments	
p_g, $1 - p_g$	Probability of government inspection or non-inspection
R_g	Benefit of government when manufacturers sell high-quality products
c_g	Cost of inspection
F_L	Fines for low-quality NEVs
L_{g1}, L_{g2}	Loss of non-inspection when manufacturers sell low-quality NEVs
For manufacturers	
$\theta, 1-\theta$	Probability of high-or low-quality NEVs
R_i	Benefit of high- or low-quality NEVs
C_i	Production cost of high- or low-quality NEVs
$P(m_j\|H)$ $P(m_j\|L)$	Conditional probabilities of manufacturers
$P(H\|m_j)$ $P(L\|m_j)$	Posteriori probabilities of manufacturers
For consumers	
P_c, $1 - P_c$	Probability of consumers' consumption or non-consumption
R_c	Benefit of buying high-quality NEVs
C_{ci}	Selection cost of high- or low-quality NEVs

Assumption 2. The strategy set of manufacturers is $m_j = (m_1, m_2) =$ (sales, non-sales), where m_1 is the sales, and m_2 is the non-sales, and the corresponding probabilities are p_m and $1 - p_m$. We set the benefit of the sales of different products as R_i, and the production cost as C_i. If the governments choose an inspection strategy, the low-quality products produced by manufacturers will be punished, and the penalty is designated as F_L. For example, on 7 February 2017, the Ministry of Industry and Information Technology issued a new ticket for NEV fraudulent compensation manufacturers and announced administrative penalty decisions for seven fraudulent repair manufacturers, including Jinhua Youth Automobile and Chongqing Lifan.

Assumption 3. The behavior set of the governments for environmental regulation is $b_j = (b_1, b_2) =$ (inspection, non-inspection). The probabilities of governments inspection and non-inspection are P_g and $1 - P_g$, respectively. We define the inspection cost as C_g, as a constant. Here, we assume that $F_L > C_g$. If manufacturers fail to take green actions, then the governments should bear the loss of non-inspection. There are two scenarios. The first is that manufacturers produce low-quality products and sell them, but governments do not inspect low-quality products. At this time, even though consumers are not buying, there are inferior products on the market. Therefore, governments will be punished by the higher authorities for the lack of inspection. The losses that the government should bear is denoted by L_{g2}. In the second scenario, consumers buy inferior products. In addition to being punished by superiors, governments can also suffer loss of reputations as consumers distrust them because of poor regulation. L_{g1} is the losses of governments when consumers purchase NEVs. Here, we know that $L_{g1} > L_{g2}$.

Assumption 4. The strategy set of consumers is $x_j = (x_1, x_2) =$ (consumption, non-consumption). The benefit of buying high-quality NEVs is represented by R_c. The cost of consumers' investment in the selection and confirmation of product quality is given by C_{ci} e.g., time and effort. To purchase high-quality NEVs, consumers compare the performance of different brands and products.

Assumption 5. The conditional probabilities of the products are $P(m_j|H)$ and $P(m_j|L)$. The consumers will update their beliefs by following the Bayesian rule, where the posteriori probabilities

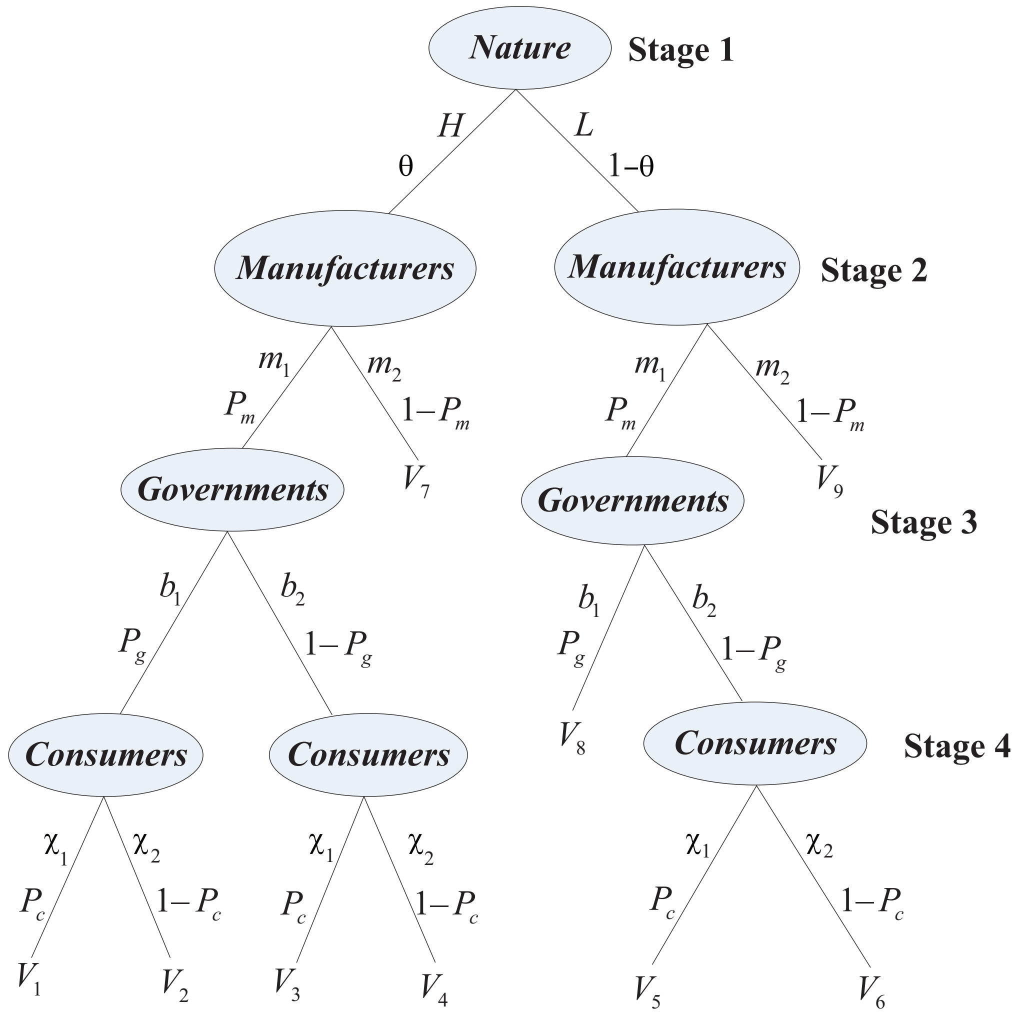

FIGURE 2 | Bayesian game among governments, manufacturers, and consumers.

are denoted by $P(H|m_j)$ and $P(L|m_j)$. The above parameters and implications are summarized in **Table 2**.

Model Construction

In this section, the game process among governments, manufacturers and consumers is analyzed. **Figure 2** illustrates the game tree of the three players on the basis of their strategic combinations. The Bayesian game process includes four stages, which can be clearly expressed.

Referring to the game built by Xu L. et al. (2019), we analyze the regulation of the circulation market of product quality, which is a prior-regulation. We set the game order beginning in stage 1. In this stage, the game participant "Nature" randomly picks a possible type of product (for example, high-product NEVs have the probability θ). In stage 2, manufacturers completely know their types of products, while the other two game players do not. Manufacturers then proceed to choose the action from the strategy set. In stage 3, governments receive the signal of the manufacturers' action, speculate on the types of products, and then determine further action that would gain them the most profit. In stage 4, consumers finally choose one strategy.

Overall, the payoffs of governments, manufacturers, and consumers can be obtained according to the aforementioned assumptions. **Table 3** gives the payoffs in different nodes.

TABLE 3 | Payoffs of governments, manufacturers, and consumers.

Node	Manufacturers	Governments	Consumers
V_1	$R_H - C_H$	$R_g - C_g$	$R_c - C_{cH}$
V_2	$-C_H$	$R_g - C_g$	0
V_3	$R_H - C_H$	R_g	$R_c - C_{cH}$
V_4	$-C_H$	R_g	0
V_5	$R_L - C_L$	$-L_{g1}$	$-C_{cL}$
V_6	$-C_L$	$-L_{g2}$	0
V_7	$-C_H$	0	0
V_8	$-C_H - F_L$	$F_L - C_g$	0
V_9	$-C_L$	0	0

Equilibrium Solution

The equilibrium solution of the dynamic game can be solved by using reverse induction (Chen et al., 2011). We analyze this game by considering the condition of separating equilibrium. If "Nature" chooses the high-quality NEVs, then the manufacturers will implement the pure strategy, which means $P(m_1|H) = 1$. If low-quality NEVs are chosen, then the manufacturers will choose to sell with the probability of δ, that is, $P(m_1|L) = \delta$. According to the Bayesian rule, we can obtain the posteriori probabilities $P(H|m_1)$ and $P(L|m_1)$ as follows:

$$P(H|m_1) = \frac{P(m_1|H) * P(H)}{P(m_1|H) * P(H) + P(m_1|L) * P(L)} = \frac{\theta}{\theta + (1-\theta)\delta}$$

$$P(L|m_1) = \frac{P(m_1|L) * P(L)}{P(m_1|H) * P(H) + P(m_1|L) * P(L)} = \frac{(1-\theta)\delta}{\theta + (1-\theta)\delta}$$

If manufacturers choose to sell low-quality products, then the governments will choose to conduct or not conduct an inspection, and the expected utility functions of the manufacturers will be denoted by $E_m(b_1, m_1|L)$ and $E_m(b_2, m_1|L)$, respectively. These expected utility functions are:

$$E_m(b_1, m_1|L) = -C_L - F_L,$$

$$E_m(b_2, m_1|L) = p_c(R_L - C_L) + (1-p_c)(-C_L).$$

Then, the whole expected utility function of manufacturers that sell low-quality NEVs can be obtained:

$$E_m(m_1|L) = p_g * E_m(b_1, m_1|L) + (1-p_g) * E_m(b_2, m_1|L)$$

When manufacturers select the non-sales strategy, we derive the expected utility functions of manufacturers as $E_m(m_2\,|L) = -C_L$.

The expected utility $E_m(m_1|L)$ equals the expected profit $E_m(m_2|L)$, and $E_m(m_1|L) = E_m(m_2|L)$ yields the Bayesian equilibrium probability of consumption p_c^*, that is, $p_c^* = \frac{p_g F_L}{(1-p_g)R_L}$. Therefore, the equilibrium probability of the non-consumption of consumers is $1 - p_c^* = 1 - \frac{p_g F_L}{(1-p_g)R_L}$.

When $p_c \in (p_c^*, 1]$, and $E_m(m_1|L) > E_m(m_2|L)$, $p_m = 1$ can become the optimal strategy, and the optimal response strategy for manufacturers is to sell low-quality NEVs. When $p_c \in [0, p_c^*)$, the optimal strategy of manufacturers is m_1, that is, $p_m = 0$. If $p_c = p_c^*$, then it makes no difference which strategy the manufacturers select. Hence, the different scenarios can be expressed as follows:

$$P_m = \begin{cases} 1 & if \quad P_c > P_c^* \\ [0, 1] & if \quad P_c = P_c^* \\ 0 & if \quad P_c < P_c^* \end{cases}.$$

The equilibrium probability of consumers is affected not only by fines for low-quality NEVs, but also by the benefit of low-quality NEVs. Additionally, it is still influenced by the probability of government regulation.

Similarly, for governments, the expected utility when they choose inspection and non-inspection are denoted by $E_g(b_1|m_1)$ and $E_g(b_2|m_1)$, respectively. By using **Table 3**, we have the following equations:

$E_g(b_1|m_1) = p(H|m_1)(R_g - C_g) + p(L|m_1)(F_L - C_g) = \frac{\theta}{\theta+(1-\theta)\delta}(R_g - C_g) + \frac{(1-\theta)\delta}{\theta+(1-\theta)\delta}(F_L - C_g)$

$E_g(b_2|m_1) = p(H|m_1)R_g + p(L|m_1)p_c(-L_{g1} - L_{g2}) = \frac{\theta}{\theta+(1-\theta)\delta}R_g + \frac{(1-\theta)\delta}{\theta+(1-\theta)\delta}(-L_{g1} - L_{g2})$ With $E_g(b_1|m_1) = E_g(b_2|m_1)$, we obtain the equilibrium probability of the manufacturers selling the low-quality NEVs, δ^*:

$$\delta^* = \frac{\theta C_g}{(1-\theta)[F_L - C_g + p_c(L_{g1} + L_{g2})]}.$$

According to the optimal equilibrium probability of manufacturers $\delta^* = \frac{\theta C_g}{(1-\theta)[F_L - C_g + p_c(L_{g1}+L_{g2})]}$. When $\delta > \delta^*$ and $E_g(b_1|m_1) > E_g(b_2|m_1)$, the optimal strategy is $p_g = 1$; at this point, the optimal strategy for the governments is to perform an inspection. When $\delta > \delta^*$, $p_g = 0$ is the optimal strategy, that is, the governments will choose non-inspection; if the optimal strategy is $\delta = \delta^*$, then it does not matter which strategy the governments choose. The above analysis can be expressed by:

$$P_g = \begin{cases} 1 & if \quad \delta < \delta^* \\ [0, 1] & if \quad \delta = \delta^* \\ 0 & if \quad \delta > \delta^* \end{cases}.$$

The equilibrium probability shows that the optimal equilibrium probability of manufacturers is due to several factors, mainly influenced by the governments' behavioral strategies. That includes the regulation cost, fines for low-quality NEVs, and governmental losses of non-inspection when manufacturers sell low-quality NEVs.

(3) For consumers, the expected utility of consumers who choose or do not choose the consumption of NEVs will be denoted by $E_c(x_1|m_1)$ and $E_c(x_2|m_1)$ respectively. These expected utility functions are:

$$E_c(x_1|m_1) = p(H|m_1)(R_c - C_{cH}) + p(L|m_1)(1-p_g)(-C_{cL}) = \frac{\theta}{\theta+(1-\theta)\delta}(R_c - C_{cH}) + \frac{(1-\theta)\delta}{\theta+(1-\theta)\delta}(1-P_g)(-C_{cL}),$$

$$E_c(x_2|m_1) = 0.$$

When $E_c(x_1|m_1) = E_c(x_2|m_1)$, we can obtain the equilibrium probability of the governments' inspection as $P_g^* = 1 - \frac{\theta(Rc - C_{cH})}{(1-\theta)\delta C_{cL}}$. Therefore, the equilibrium probability of governments' non-inspection is $1 - P_g^* = \frac{\theta(Rc - C_{cH})}{(1-\theta)\delta\, C_{cL}}$.

When $P_g > P_g^*$ and $E_c(x_1|m_1) > E_c(x_2|m_1)$, $p_c = 1$ is the optimal consumer strategy. When this condition is met, the consumers' optimal strategy is the consumption of NEVs. Alternatively, when $P_g < P_g^*$, $p_c = 0$ becomes the optimal strategy, and the consumers will choose non-consumption. When

$P_g < P_g^*$, it does not matter which strategy the consumers choose. The above analysis can be expressed as follows:

$$P_c = \begin{cases} 1 & if \quad P_g < P_g^* \\ [0,1] & if \quad P_g = P_g^* \\ 0 & if \quad P_g > P_g^* \end{cases}.$$

The equilibrium probability of the government's inspection is affected by consumer behavior strategy. The benefit of buying high-quality NEVs and the selection cost of high-or low-quality NEVs are important influencing factors.

ANALYSIS OF THE EQUILIBRIUM RESULTS OF THE DYNAMIC BAYESIAN GAME

Through solving and analyzing the equilibrium solution of the tripartite game model, the most important influencing factors of strategy selection analysis are carried out for each party. The internal correlation between the game participants and strategy selection is discussed in this section.

Equilibrium Probability of Manufacturers

The equilibrium probability of manufacturers selling the low-quality NEVs is associated with C_g, F_L, L_{g1} and L_{g2}.

Proposition 1: The probability of manufacturers selling the low-quality NEVs, δ^*, increases as, C_g, increases.

By calculating the partial derivative of δ^*, we calculate that

$$\frac{\partial \delta^*}{\partial C_g} = \frac{\theta(1-\theta)[F_L + p_c(L_{g1} + L_{g2})]}{\{(1-\theta)[F_L - C_g + p_c(L_{g1} + L_{g2})]\}^2}$$

Given that $\theta \in [0, 1]$, it is concluded that $\frac{\partial \delta^*}{\partial C_g} > 0$.

From Proposition 1, an increased cost of government inspection lead to an increase im manufacturers with inferior eco-friendly operations. Because the increased cost of government inspection will reduce the probability of inspection, so it will increase the rate of low-quality products. The manufacturers do not care about the risk of deception in NEVs and degrade the quality of their products. In other words, the higher the regulation cost of NEVs, the more likely it is that manufacturers will commit fraud. Accordingly, there will be no reduction in carbon emissions.

Proposition 2: The probability of manufacturers, δ^*, decreases as the losses L_{g1}, L_{g2} and governmental fines, F_L increase.

Given the solutions for L_{g1}, L_{g2} and F_L for the first derivatives of δ^*, we have

$$\frac{\partial \delta^*}{\partial L_{g1}} = \frac{-(1-\theta)p_c}{\{(1-\theta)[F_L - C_g + p_c(L_{g1} + L_{g2})]\}^2} < 0,$$

$$\frac{\partial \delta^*}{\partial L_{g2}} = \frac{-(1-\theta)p_c}{\{(1-\theta)[F_L - C_g + p_c(L_{g1} + L_{g2})]\}^2} < 0,$$

$$\frac{\partial \delta^*}{\partial F_L} = \frac{-(1-\theta)}{\{(1-\theta)[F_L - C_g + p_c(L_{g1} + L_{g2})]\}^2} < 0.$$

Proposition 2 illustrates that whether consumers purchase NEVs, the losses of governments that affect the behavior of manufacturers are the same; when these losses increase, the problem of illegal emissions gets better. Proposition 2 also reveals that enhancing fines will decrease illegal emission behaviors. That is, governments contribute to ensuring product quality when they strengthen the punishment mechanism.

Equilibrium Probability of Governments

The equilibrium probabilities of governments' inspection, P_g^*, are determined by R_c, C_{cH} and C_{cL}.

Proposition 3: The probability of governments' inspection, P_g^*, decreases as the consumers' benefit of high-quality NEVs, R_c, and the selection cost of low-quality NEVs, C_{cL}, increases.

The first derivatives of the P_g^* on R_c and C_{cL} are as follows:

$$\frac{\partial P_g^*}{\partial R_c} = \frac{-\theta}{[\theta(1-\theta)\delta C_{cL}]^2} < 0,$$

$$\frac{\partial P_g^*}{\partial C_{cL}} = \frac{-(1-\theta)\delta}{[(1-\theta)\delta C_{cL}]^2} < 0.$$

Proposition 3 shows that as the benefit of high-quality NEVs and the cost of low-quality NEVs increases, consumers will benefit from purchasing the conforming products and will buy the NEVs. Thus, the probability of governments' inspection will be reduced, and the governments will be unlikely to regulate the manufacturers. Meanwhile, when the cost of identifying low-quality products is low, it is easy for consumers to find substandard products and buy high-quality products. The probability of governments' inspection can also be decreased.

Proposition 4: The probability of governments' inspection, P_g^*, increases as the selection cost of high-quality NEVs, C_{cH}, increases.

The solution for C_{cH} for the first derivatives of P_g^* is as follows:

$$\frac{\partial P_g^*}{\partial C_{cH}} = \frac{\theta}{(1-\theta)\delta C_{cL}} > 0.$$

Proposition 4 gives the relationships between the cost of consumption and the probability of governmental inspection. As the values of C_{cH} grow, P_g^* will increase. More specifically, when the selection cost of buying high-quality NEVs is high, and the information asymmetry of product quality is more serious, consumers will be more likely to buy low-quality NEVs. At this point, the government will increase the probability of regulation.

Equilibrium Probability of Consumers

The equilibrium probability of consumers is related to F_L and R_L.

Proposition 5: The probability of consumers' consumption P_c^* is an increasing function of F_L.

The first derivative of the equilibrium probability of consumers in terms of F_L is obtained by:

$$\frac{\partial P_c^*}{\partial F_L} = \frac{p_g}{(1-p_g)R_L} > 0.$$

From Proposition 5, it is clear that the more the governments penalize manufacturers of substandard products, the less they

TABLE 4 | Changes in equilibrium probability as model parameters increase.

Equilibrium probability		Parameters
Manufacturers	δ*	C_g F_L L_{g1} L_{g2} + − − −
Governments	Pg^*	R_c C_{CH} C_{CL} − + −
Consumers	Pc^*	R_L F_L − +

*+, Increase; −, Decrease. * is the identification of equilibrium probability.*

will violate the rules, and thus the more likely that consumers will choose to buy NEVs. This case is good for governments because the lower the carbon emission reduction, the higher the environmental quality.

Proposition 6: The probability of consumers' consumption, P_c^*, is a negative function of R_L.

The first derivative of P_c^* in terms of R_L is as follows:

$$\frac{\partial P_c^*}{\partial R_L} = \frac{-(1-p_g)}{[(1-p_g)R_L]^2} > 0.$$

Proposition 6 reveals that the higher the low-quality products that manufacturers produce, the more likely they are to forego compliance emissions. To consumers, the probability of consumers' consumption of high-quality products will be reduced. In other words, when manufacturers make high profits by producing low-quality products, they will produce more of these products. Manufacturers have no incentive to produce high-quality products, and consumers are inclined to buy low-quality products.

In summary, the changes in equilibrium probability as the model parameters increase are presented in **Table 4**.

CONCLUSION

In the incomplete information dynamic game, the Bayesian game model is used to describe and explain the game mechanism chosen by participants in NEVs. We provide optimal decisions for manufacturers, governments, and consumers, and analyze their key influencing factors. The results of this research reveal the following: (1) The strategy of manufacturers depends on the inspection cost, the punishment incurred, and the losses of the governments for low-quality NEVs. (2) The strategy of governments is influenced by the production cost of high-and low-quality NEVs and the benefit of the manufacturers from selling high-quality products. (3) The strategy of consumers is related to the fines and benefits for low-quality products by manufacturers. On the basis of the above conclusions, we provide the following recommendations for governments to improve the quality of NEVs.

First, governments should enhance their constraint penalty management mechanisms and punishment policies. According to Proposition 2 and Proposition 5, the fines of NEVs are an important factor affecting the game equilibrium of both manufacturers and consumers. They are the key to comprehensive environmental governance and are an effective means of encouraging manufacturers to abide by environmental policies. Additionally, in consideration of Proposition 1, reducing the cost of government regulation will improve product quality. Therefore, to realize the integration of online and offline regulations, governments can set up a regulatory platform for manufacturers. By collecting data from social media or consumers to update information from the platform, once the manufacturers' violation is discovered, the government can investigate the violation and deal with it accordingly. This is an effective way to reduce the cost of regulation especially when governments have budgetary constraints.

Second, it is also necessary for the government to enhance the ability of consumers to identify product quality. From Proposition 3 to Proposition 4, we know that reducing the cost for consumers to distinguish product quality cannot only reduce the government supervision input, but also reduce the information asymmetry of product quality. On the one hand, through timely disclosure of regulatory results of NEVs, it can provide consumers with information and channels to identify product quality. On the other hand, strengthening the product quality certification provides information support for consumers to buy products and introduces clear compensation measures for low-quality products to better protect the legitimate rights of consumers.

Third, the manufacturers' production costs of NEVs should be reduced. It is well known that producing NEVs with carbon emission reduction is often extremely costly for manufacturers (Gouda et al., 2016). In the market competition, the NEVs industry needs to rely on support from the government (Olson, 2018). To reduce the high levels of risk and uncertainty, governments should make preferential policies to support manufacturers. For example, the appropriate subsidies can provide incentives and encourage manufacturers to develop low-carbon emission technologies. On the contrary, manufacturers that produce high-carbon emission products need to pay taxes, such as pollution taxes.

Lastly, there should be an increase in consumers' returns on NEVs. Consumers must realize some benefits, including reduced environmental degradation, for them to be willing to take on the burden of additional costs. Thus, many governments have subsidized consumers who purchase NEVs. For example, in China, consumers can receive certain government subsidies when they purchase NEVs. Meanwhile, through improved consumer environmental awareness, consumers are now more familiar with carbon-emission products and are willing to pay extra for NEVs.

The study expounds on the dynamic interaction among government regulation, manufacturer production, and consumer consumption. Some recommendations on the formulation and improvement of environmental policies for governments are provided. Several future research directions for this study are likewise presented. The behaviors of governments, manufacturers, and consumers can be analyzed through empirical research, which may provide more objective and practical results. Extending the tripartite game to the case with heterogeneous game players could also be a challenging and interesting direction for future research.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design, read, and approved the final manuscript.

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