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Green Product Quality Supervision Strategy in Online Shopping With Consumer Evaluation and Complaint

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Green consumption is an important foundation for achieving stable and long-term economic development goals. With the rapid development of e-commerce and people's widespread attention to sustainability, more and more consumers purchase green products online. Therefore, we consider consumer feedback mechanisms including evaluation and complaint and construct an evolutionary game model of green product quality supervision with the participation of governmental supervision department, third-party e-commerce platform, online seller and consumer, which analyzes the four parties' evolutionary stable strategies. To verify the theoretical results, we conduct a numerical simulation by *Matlab 2020b*. Moreover, we study the conditions that make evolutionary stable strategy combination exist based on *Lyapunov's First Method*. And we find that when consumer chooses complaint, (0, 0, 1) is likely to become an only evolutionary stable strategy combination. At this time, the online seller chooses to provide high-quality green product, third-party e-commerce platform chooses not to strengthen inspection, and governmental supervision department chooses to strictly supervise. Conversely, when the consumer chooses no complaint, (1, 0, 0) and (0, 0, 1) may become an evolutionary stable strategy combination. At this time, the online seller cannot be stable in providing high-quality green product. What's more, governmental supervision department increases the penalty, which can incentivize a third-party e-commerce platform to strengthen inspection. Third-party e-commerce platform increases the reward and can promote online seller to provide high-quality green product. On the one hand, this paper enriches the theoretical basis of online shopping green product quality supervision. On the other hand, compared with existing literature, it extends the main body of the evolutionary game to four paries and broadens the application scope of the game model. In addition, it has put forward feasible suggestions for the government supervision department to strengthen the quality supervision, and provided decision-making support for the third-party e-commerce platform to assume the responsibility of quality inspection.

Keywords: green product quality supervision, online shopping, consumer evaluation, consumer complaint, evolutionary game

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INTRODUCTION

The growth of e-commerce is transforming shopping consumption from offline to online. According to *Global E-commerce Data Report*, online retail transactions of China, the United States, the United Kingdom, and Japan were 1,309.5 billion dollars, 520 billion dollars, 291 billion dollars, and 179 billion dollars in 2019, with growth rates of 25.5, 15.8, 11.1, and 19.1%, respectively. The prosperous development of online shopping provides a broad platform for green products. *Green product* refers to what meets specific environmental protection requirements during the entire process of production, processing, transportation, consumption, and recycling, and has the lowest harm to the ecological environment, the highest resource utilization, and the least energy consumption. Online shopping green product not only brings great convenience but also satisfies consumers' demands for environmental protection. Consumers are paying more and more attention to green product quality. However, there are some serious problems, such as the lack of government supervision, insufficient inspection of third-party e-commerce platform, irregularities in green product certification standards, illegal sales of online seller, and invalid complaint of consumers.

In some countries, such as China, the United States, the United Kingdom, and Japan, many corresponding measures have been taken. China began to implement *the e-commerce law* in 2019, which clarified the issues of counterfeit sales and consumer rights protection. The United States has established a across-departmental e-commerce management agency and government e-commerce working group, implemented strict unreasonable return system, and also built the Better Business Bureau for consumer complaint and rights protection. The United Kingdom has established a special office which is responsible for monitoring whether companies have reached the relevant standards of product and service, and implemented some laws and regulations, such as the *E-commerce Regulations* and the *United Kingdom Consumer Protection Act*, which have provided a basis for the e-commerce supervision. Japanese e-commerce started late, but its development speed is rapid. The Japanese government has formulated a series of laws and regulations, such as *Electronic Consumer Contract Law*, *Resolution Framework for Consumer Disputes in Electronic Commerce*, which intensify the supervision of e-commerce transactions. Despite many countries having made great efforts, online shopping green product quality problems have not been solved. There is a need to further study how to achieve effective supervision.

More and more practice show that consumer feedback is becoming increasingly important in online shopping, and product quality problems need to be solved by multiple parties (Li et al., 2015). Therefore, this paper considers a consumer feedback mechanism including evaluation and complaint and constructs an evolutionary game model with the participation of governmental supervision department, third-party e-commerce platform, online seller, and consumer. We analyze each party's evolutionary stable strategy and factors' influence on four parties' strategic choices. Based on the *Lyapunov's First Method* (Liu et al., 2015), we study the conditions that make evolutionary stable strategy combination exist, and verify our theoretical analysis results with numerical simulation by *Matlab 2020b*. This paper aims to solve the following questions: How does consumer evaluation and complaint influence each party's strategic choice? How does a third-party e-commerce platform design reasonable reward and penalty to incentivize the online seller to provide high-quality green products? How does a governmental supervision department make effective supervision strategies to improve online shopping green product quality?

The rest of our paper is organized as follows. In *Literature Review*, we review relevant research on online shopping green product quality. We make assumptions and construct an evolutionary game model in *Model Assumptions and Construction*. In *The Stability Analysis of Strategic Choices*, each party's strategy stability is analyzed. In *Stability Analysis of Strategy Combination*, we analyze the strategy combination's stability based on the *Lyapunov's First Method*. In *Numerical Simulation Analysis*, we conduct numerical simulation by *Matlab 2020b*, which analyzes factors' influence on the evolutionary stable strategy combination. At last, suggestions and advices are provided in *Summary*. Throughout the paper, from the abstract, introduction, literature review, method, to the final conclusion, we refer to some excellent references to improve the study (Abbas et al., 2019; Aman et al., 2019; Mubeen et al., 2020; Abbasi et al., 2021).

LITERATURE REVIEW

Online Shopping Product Quality

As we know, the spread of COVID-19 creates disruption, uncertainty, complexity, and ambiguity in all walks of life (Azizi et al., 2021). People's demand for online shopping has greatly increased. However, product quality is also worrying. The serious information asymmetry between consumer and online seller is the root cause of online shopping product quality problems. Information about product quality will affect consumers' purchase intention (Zhou et al., 2018), and the consumer usually makes assessment through the information about product quality provided by a third-party e-commerce platform and online seller (Mavlanova et al., 2012). For the online seller, disclosing the transaction data timely makes it easier to attract customers (Subramanian and Rao, 2016). Correct information is indispensable to dispel uncertainty (Abbas et al., 2021). Information sharing helps companies become more dynamic, innovative, and competitive (Abbas et al., 2019). Competitive online sellers tend to disclose as much product information as possible (Tao et al., 2018). Low-quality online sellers, however, may use the information transmission mechanism to pretend to be a high-quality seller and sell low-quality product (Fouliras, 2013), which leads to increasingly serious online shopping product quality problems. As consumers' awareness of rights protection increases, the return rate has gradually increased, resulting in the increasing cost of stakeholders' return management (Shang et al., 2017). Therefore, a third e-commerce platform has the motivation to strengthen inspection of online seller's qualification and provide the consumer with reliable information (Loureiro et al., 2012). But actually, in order to pursue higher profits, the collusion between third-party e-commerce platform and online seller usually occurs (Park and Ju, 2016).

Online shopping product problems are very common in many countries, which have aroused many researchers' attention. They have proposed various mechanisms such as supervision mechanism (Li et al., 2018), revenue sharing mechanism (Zhang et al., 2019), return management system (Griffis et al., 2012; Seung, 2014), supply chain management system (Kaynak and Hartley, 2008; Zhu, 2020), reward and penalty system (He and Zhu, 2020). Scholars usually conduct research from a single party perspective. But in fact, the product quality problems involve multiple parties. Therefore, this paper constructs an evolutionary game model involving four parties.

Green Product

In the late 1980s and early 1990s, the term of green was created in the marketing field (Wang et al., 2020). With the progress of society, balancing the relationship between economic development and environmental protection has become a hot topic (Bai et al., 2020). Correspondingly, green and sustainability are considered to be particularly common in production, consumption, and other fields. From the perspective of the consumer, the consumer pays more attention to sustainability and environmental protection and prefers to buy green products (Hong and Guo, 2019). However, green product quality still falls short of consumers' expectations. From the perspective of the seller, compared with non-green product, green product does have moral advantages while it has disadvantages in price (Dixon and Mikolon., 2020). The R&D, production, sales, recycling, and other links of green product all require higher costs, which may discourage producer and seller from improving product quality. From the perspective of government, government usually provides higher subsidies and lower taxes to producer and seller (Sana, 2020). And the continuous improvement of green standards also can improve a green product's environmental benefits (Gao et al., 2020). Strict enforcement of regulations by government in practice is an effective incentive measure. What needs to be paid attention to is that government should implement regulations carefully, because overly strict regulations may cause producer and seller to be reluctant to innovate, and gain higher profits at the cost of reducing overall environmental performance (Maryam and Hossein, 2018). Market competition can stimulate producer and seller to make choices that meet public requirements (Guo et al., 2019). It can be seen that most of the existing researches study product quality supervision, but are less involved in green product quality supervision, so this paper analyzes how to supervise green product quality in online shopping.

Consumer Evaluation

Positive evaluation is usually related to the product itself (Ahmad and Laroche, 2016), and negative evaluation has a great impact on management and service quality (Chevalier et al., 2018). Effective social evaluation can reduce consumer losses (Zheng et al., 2019). The more serious the information asymmetry, the more online evaluation can reduce the uncertainty of product quality (Zhang et al., 2017). The consumer's perception of product quality will be delayed due to information asymmetry (Li et al., 2018), but online evaluation can help consumers get some product quality information in advance, thereby reducing risk and uncertainty (Yang et al., 2016). Therefore, consumers are more inclined to trust online evaluation than information provided by third-party e-commerce platform and online seller. In addition, online evaluation is not only valuable for consumers to make purchasing decisions (Fu et al., 2018) but also helpful for the online seller to attract consumers (Siering et al., 2018), because customer's trust can significantly affect the seller's commercial reputation (Song et al., 2019). The above research simply focus on the importance of consumer evaluation in online shopping but does not consider consumer complaint. This paper considers both consumer evaluation and complaint, and more comprehensively analyzes the role of consumer in online shopping green product quality supervision.

Generally, although some empirical research has analyzed the quality supervision of the online shopping green product, there still lacks an appropriate mathematical model to study each party's stable strategy. Additionally, there are few studies involving multiple parties and considering consumer feedback mechanism.

Therefore, this paper considers consumer feedback mechanism and constructs a four-party evolutionary game model, which analyzes four parties' evolutionary stable strategies, studies the conditions that make evolutionary stable strategy combination exist based on the *Lyapunov's First Method*, and verifies theoretical analysis results with numerical simulation by *Matlab 2020b*.

MODEL ASSUMPTIONS AND CONSTRUCTION

This paper constructs a four-party evolutionary game model. The structure relationship of green product quality supervision in online shopping is shown in **Figure 1**.

Model Assumption

The four parties are governmental supervision department, third-party e-commerce platform, online seller, and consumer. Governmental supervision department's strategic choice space is {SS, LS}, i.e., {Strictly Supervise, Loosely Supervise}. Third-party e-commerce platform's strategic choice space is {SI, NSI}, i.e., {Strengthen Inspection, Not Strengthen Inspection}. Online seller's strategic choice space is {PH, PL}, i.e., {Provide High-quality Green Product, Provide Low-quality Green Product}. Consumer's strategic choice space is {C, NC}, i.e., {Complain, Not Complain}.

Governmental supervision department chooses to strictly supervise with the probability of $x(0 \leq x \leq 1)$, and to loosely supervise with the probability of $(1-x)$. Third party e-commerce platform chooses to strengthen inspection with the probability of $y(0 \leq y \leq 1)$, and not to strengthen inspection

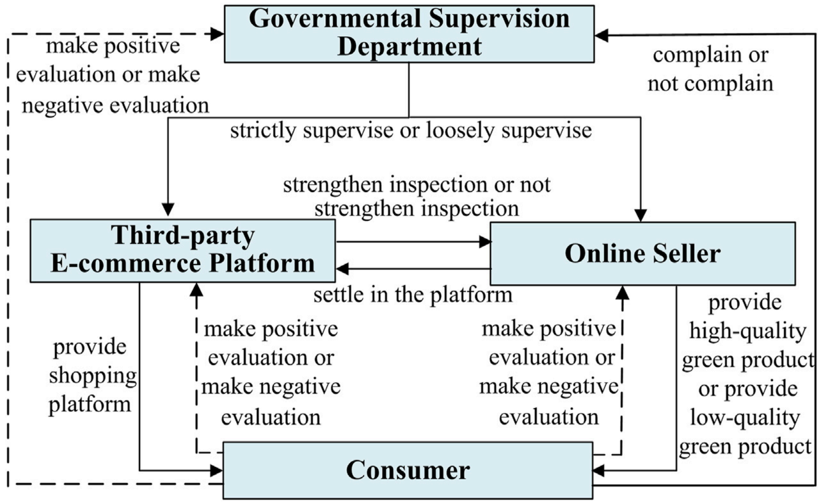

FIGURE 1 | The structure relationship of green product quality supervision in online shopping.

with the probability of $(1-y)$. Online seller chooses to provide high-quality green product with the probability of $p(0 \le p \le 1)$, and to provide low-quality green product with the probability of $(1-p)$. Consumer chooses to complain with the probability of $q(0 \le q \le 1)$, and not to complain with the probability of $(1-q)$.

Governmental supervision department's cost of strict supervision is C_{gh}. Third-party e-commerce platform's cost of strengthening inspection is C_{ph}, and the cost of not strengthening inspection is $C_{pl}(C_{ph} > C_{pl} > 0)$. Online seller's cost of providing high-quality green product is C_{sh}, and the cost of providing low-quality green product is $C_{sl}(C_{sh} > C_{sl} > 0)$.

When a green product is sold, online seller's revenue is V_s, and the third-party e-commerce platform's revenue is V_p. When third-party e-commerce platform strengthens inspection, if the online seller provides a high-quality green product, the consumer will get the utility R_c, the online seller will get rewards J from the third-party e-commerce platform. If the online seller provides low-quality green product, the third-party e-commerce platform will prohibit low-quality green product and punish online seller, and the penalty is P.

When the online seller provides a low-quality green product, the third-party e-commerce platform does not strengthen inspection, and the governmental supervision department chooses loose supervision, the low-quality green product will enter the market, and the consumer will undertake the loss L_c. If the consumer chooses to complain, he will pay the cost C_c and receive compensationB_c from the online seller ($B_c > C_c$). The superior department will punish the governmental supervision department, the penalty cost is F_g; the governmental supervision department will also punish third-party e-commerce platform and online seller, and the penalty costs areF_p andF_s, respectively. The consumer will make negative evaluation, the reputation losses of governmental supervision department, third-party e-commerce platform, and online seller are N_g, N_p and N_s, respectively.

When the online seller provides a low-quality green product, the third-party e-commerce platform strengthens inspection or governmental supervision department strictly supervise, a low-quality green product is prohibited from entering the market, and the consumer's purchasing needs have not been met, the consumer's negative utility is N. When an online seller provides a high-quality green product, the consumer will make positive evaluation, and the reputation value premiums of governmental supervision department, third-party e-commerce platform, and online seller are R_g, R_p and R_s, respectively.

The parameters setting and their meanings are shown in **Table 1**.

Model Construction

This paper considers a consumer feedback mechanism including evaluation and complaint, and constructs an evolutionary game model. The mixed game matrix for green product quality supervision in online shopping is shown in **Table 2**.

THE STABILITY ANALYSIS OF STRATEGIC CHOICES

The Stability Analysis of Governmental Supervision Department Strategic Choices

The expected profit when governmental supervision department chooses strictly supervision is E_{SS}. The expected profit when governmental supervision department chooses loosely supervision is E_{LS}. The average expected profit of governmental supervision department is $\overline{E_S}$. Replicator dynamic equation is $F(x)$ and its first-order derivative is $F'(x)$.

$$E_{SS} = yp(R_g - C_{gh}) + y(1-p)(R_g - C_{gh}) + (1-y)p(R_g - C_{gh}) + (1-y)(1-p)(R_g - C_{gh}) \tag{1}$$

$$E_{LS} = yR_g + (1-y)pR_g - (1-y)(1-p)(qF_g + N_g) \tag{2}$$

$$\overline{E_S} = xE_{ss} + (1-x)E_{LS} \tag{3}$$

TABLE 1 | Parameters setting and meanings.

Parameters	Meanings	Parameters	Meanings
x	The probability of strict supervision	$1 - x$	The probability of loose supervision
y	The probability of strengthened inspection	$1 - y$	The probability of unstrengthened inspection
p	The probability of providing high-quality green product	$1 - p$	The probability of providing low-quality green product
q	The probability of complaint	$1 - q$	The probability of not complaining
C_{gh}	The cost of strict supervision	C_{ph}	The cost of strengthening inspection
C_{pl}	The cost of not strengthening inspection	C_{sh}	The cost of providing high-quality green product
C_{sl}	The cost of providing low-quality green product	J	Rewards for online seller
P	Penalty for online seller	V_s	Online seller's revenue
V_p	Third-party e-commerce platform's revenue	B_c	Consumer's compensation
L_c	Consumer's loss after purchasing low-quality green product	R_c	Consumer' utility after purchasing high-quality green product
C_c	The cost of consumer complaint	R_s	Online seller's reputation value premium
R_g	Governmental supervision department's reputation value premium	R_p	Third-party e-commerce platform's reputation value premium
N_g	Governmental supervision department's reputation loss	N_p	Third-party e-commerce platform's reputation loss
N_s	Online seller's reputation loss	F_g	Governmental supervision department's penalty cost
F_p	Third-party e-commerce platform's penalty cost	F_s	Online seller's penalty cost
N	Consumer's negative utility		

TABLE 2 | Mixed game matrix for green product quality supervision.

		Online seller	Governmental supervision department			
			SS		LS	
			x		1 − x	
			Consumer C	NC	C	NC
			q	1 − q	q	1 − q
Third-party E-commerce Platform	SI	PH p	$R_g - C_{gh}$ $V_p + R_p - J - C_{ph}$ $V_s + R_s + J - C_{sh}$ R_c	$R_g - C_{gh}$ $V_p + R_p - J - C_{ph}$ $V_s + R_s + J - C_{sh}$ R_c	R_g $V_p + R_p - J - C_{ph}$ $V_s + R_s + J - C_{sh}$ R_c	R_g $V_p + R_p - J - C_{ph}$ $V_s + R_s + J - C_{sh}$ R_c
	y	PL $1 - p$	$R_g - C_{gh}$ $R_p + P - C_{ph}$ $-C_{sl} - P$ $-N$	$R_g - C_{gh}$ $R_p + P - C_{ph}$ $-C_{sl} - P$ 0	R_g $R_p + P - C_{ph}$ $-C_{sl} - P$ $-N$	R_g $R_p + P - C_{ph}$ $-C_{sl} - P$ 0
	NSI	PH p	$R_g - C_{gh}$ $V_p + R_p - C_{pl} - F_p$ $V_s + R_s - C_{sh}$ R_c	$R_g - C_{gh}$ $V_p + R_p - C_{pl} - F_p$ $V_s + R_s - C_{sh}$ R_c	R_g $V_p + R_p - C_{pl}$ $V_s + R_s - C_{sh}$ R_c	R_g $V_p + R_p - C_{pl}$ $V_s + R_s - C_{sh}$ R_c
	$1 - y$	PL $1 - p$	$R_g - C_{gh}$ $R_p - C_{pl} - F_p$ $-C_{sl} - F_s$ $-N$	$R_g - C_{gh}$ $R_p - C_{pl} - F_p$ $-C_{sl} - F_s$ 0	$-N_g - F_g$ $V_p - N_p - C_{pl} - F_p$ $V_s - N_s - F_s - C_{sl} - B_c$ $B_c - L_c - C_c$	$-N_g$ $V_p - N_p - C_{pl}$ $V_s - N_s - C_{sl}$ $-L_c$

$$F(x) = dx/dt = x\left(E_{SS} - \overline{E_S}\right) = x(1-x)(E_{SS} - E_{LS})$$
$$= x(1-x)\left[(1-y)(1-p)\left(R_g - qF_g - N_g\right) - C_{gh}\right] \quad (4)$$
$$F'(x) = (1-2x)\left[(1-y)(1-p)\left(R_g - qF_g - N_g\right) - C_{gh}\right] \quad (5)$$

According to the stability theorem of differential equations, the probability of SS in a stable state must satisfy $F(x) = 0$ and $F'(x) < 0$.

Proposition 1 When $q < q_0$, the evolutionary stable strategy of governmental supervision department is SS; when $q > q_0$, the evolutionary stable strategy of governmental supervision department is LS; when $q = q_0$, there is no evolutionary stable strategy of governmental supervision department. The threshold q_0 satisfies $q_0 = [(1-y)(1-p)(R_g - N_g) - C_{gh}]/(1-y)(1-p)F_g$.

Proof Let $M(q) = (1-y)(1-p)(R_g - qF_g - N_g) - C_{gh}$. Take the first-order derivative of $M(q)$with respect to $q$yields $\partial M(q)/\partial q = -(1-y)(1-p)F_g < 0$. Hence, $M(q)$ is negatively related to q. When $q < q_0$, $M(q) > 0$, $F(x)|_{x=1} = 0$ and $F'(x)|_{x=1} < 0$, then $x = 1$ is evolutionary stable strategy. When $q > q_0$, $M(q) < 0$, $F(x)|_{x=0} = 0$ and $F'(x)|_{x=0} < 0$, then $x = 0$ is evolutionary stable strategy. When $q = q_0$, $M(q) = 0$, $F(x) = 0$ and $F'(x) = 0$, no evolutionary stable strategy. The Proposition 1 shows that with the increasing of complaint probability, the evolutionary stable strategy of governmental supervision department will change from SS to LS.

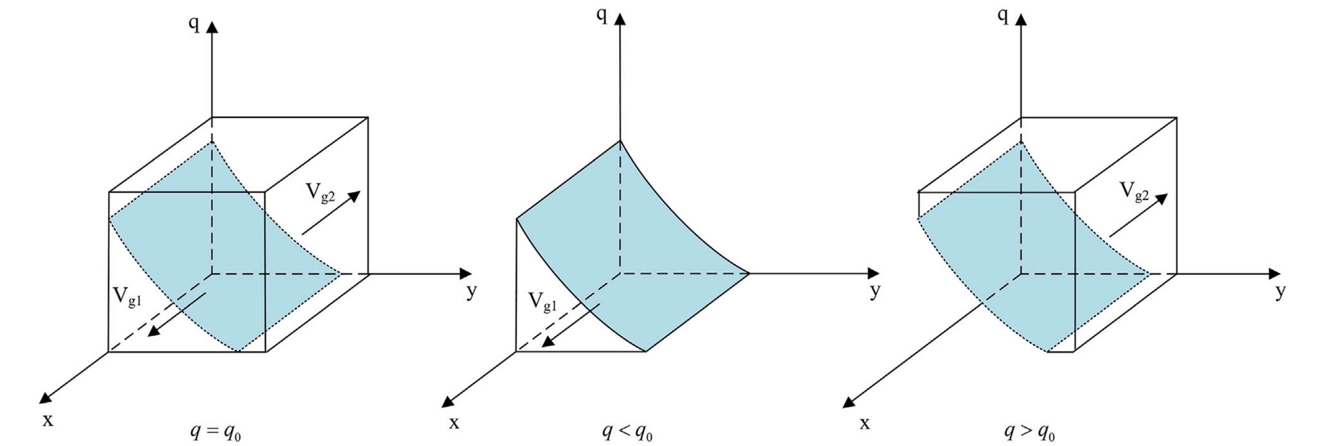

FIGURE 2 | The strategic choices of governmental supervision department.

According to Proposition 1, governmental supervision department's strategic choices are shown in **Figure 2**.

Let V_{g1} represent the probability that governmental supervision department chooses the SS strategy, and V_{g2} represent the probability that governmental supervision department chooses the LS strategy.

$$V_{g1} = \int_0^1 \times \int_0^{1-C_{gh}/((1-p)(R_g-N_g))} \frac{(1-y)(1-p)(R_g-N_g)-C_{gh}}{(1-y)(1-p)F_g} dydx = \frac{R_g-N_g}{F_g} - \frac{C_{gh}}{(1-p)F_g} + \frac{C_{gh}}{(1-p)F_g}\ln\frac{C_{gh}}{(1-p)(R_g-N_g)} \tag{6}$$

$$V_{g2} = 1 - V_{g1} = 1 - \frac{R_g-N_g}{F_g} + \frac{C_{gh}}{(1-p)F_g} - \frac{C_{gh}}{(1-p)F_g}\ln\frac{C_{gh}}{(1-p)(R_g-N_g)} \tag{7}$$

Corollary 1.1 The higher the reputation value premium brought by the consumer's positive evaluation, the higher the probability that governmental supervision department chooses the SS strategy.

Proof Take the first- order derivative of V_{g1} with respect to R_g yields $\partial V_{g1}/\partial R_g = 1/F_g - 1/((1-p)(R_g-N_g)F_g) > 0$. V_{g1} is positively related to R_g. The probability that the governmental supervision department chooses the SS strategy is positively related to the reputation value premium brought by a consumer's positive evaluation.

Corollary 1.1 indicates that the higher the reputation value premium brought by a consumer's positive evaluation, the greater the influence of that consumer's evaluation, and the higher the probability that governmental supervision department chooses the SS strategy.

Corollary 1.2 With the increasing of strict supervision cost, the probability that governmental supervision department chooses the SS strategy will decrease.

Proof Take the first-order derivative of V_{g1} with respect to C_{gh} yields $\partial V_{g1}/C_{gh} = -\frac{1}{(1-p)F_g}\left(1 - \ln\frac{C_{gh}}{(1-p)(R_g-N_g)}\right) < 0$. V_{g1} is negatively related to C_{gh}. The probability that governmental supervision department chooses the SS strategy is negatively related to the strict supervision cost.

Corollary 1.2 indicates that the increase in strict supervision cost can discourage the governmental supervision department from choosing the SS strategy.

The Stability Analysis of Third-Party e-Commerce Platform Strategic Choices

The expected profit when a third-party e-commerce platform chooses to strengthen inspection isE_{SI}. The expected profit when a third-party e-commerce platform chooses not to strengthen inspection isE_{NSI}. The average expected profit of third-party e-commerce platform is $\overline{E_I}$. Replicator dynamic equation is $F(y)$ and its first-order derivative is $F'(y)$.

$$E_{SI} = p(V_p + R_p - J - C_{ph}) + (1-p)(R_p + P - C_{ph}) \tag{8}$$

$$E_{NSI} = p(V_p + R_p - C_{pl}) + x(1-p)(R_p - C_{pl}) + (1-x)(1-p)(V_p - N_p - C_{pl} - qF_p) \tag{9}$$

$$\overline{E_I} = yE_{SI} + (1-y)E_{NSI} \tag{10}$$

$$F(y) = dy/dt = y\left(E_{SI} - \overline{E_I}\right) = y(1-y)(E_{SI} - E_{NSI}) = y(1-y)\left[R_p + P - C_{ph} - p(J + P + R_p - C_{pl}) - x(1-p)(R_p - C_{pl}) - (1-x)(1-p)(V_p - N_p - C_{pl} - qF_p)\right] \tag{11}$$

$$F'(y) = (1-2y)\left[R_p + P - C_{ph} - p(J + P + R_p - C_{pl}) - x(1-p)(R_p - C_{pl}) - (1-x)(1-p)(V_p - N_p - C_{pl} - qF_p)\right] \tag{12}$$

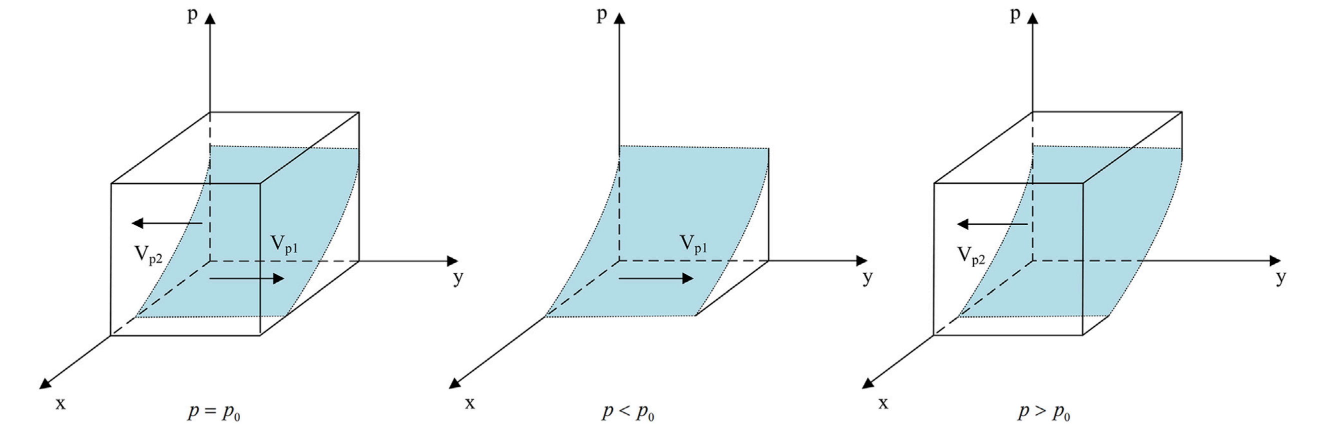

FIGURE 3 | The strategic choices of third-party e-commerce platform.

According to the stability theorem of differential equations, the probability of SI in a stable state must satisfy $F(y) = 0$ and $F'(y) < 0$.

Proposition 2 When $p < p_0$, the evolutionary stable strategy of the third-party e-commerce platform is SI; when $p > p_0$, the evolutionary stable strategy of third-party e-commerce platform is NSI; when $p = p_0$, there is no evolutionary stable strategy of third-party e-commerce platform. The threshold p_0 satisfies $p_0 = 1 - (C_{ph} - C_{pl})/[P + J + (1 - x)(R_p + N_p + qF_p - V_p)]$.

Proof Let $T(p) = R_p + P - C_{ph} - p(J + P + R_p - C_{pl}) - (1 - x)(1 - p)(V_p - N_p - C_{pl} - qF_p) - x(1 - p)(R_p - C_{pl})$.

Take the first-order derivative of $T(p)$with respect to p yields $\partial T(p)/\partial p = -(1 - x)(R_p + N_p + qF_p - V_p) - J - P < 0$. That is, $T(p)$ is negatively related to p. When $p < p_0$, $T(p) > 0$, $F(y)\big|_{y=1} = 0$ and $F'(y)\big|_{y=1} < 0$, then $y = 1$ is evolutionary stable strategy. When $p > p_0$, $T(p) < 0$, $F(y)\big|_{y=0} = 0$ and $F'(y)\big|_{y=0} < 0$, then $y = 0$ is evolutionary stable strategy. When $p = p_0$, $T(p) = 0$, $F(y) = 0$ and $F'(y) = 0$, no evolutionary stable strategy.

The Proposition 1 shows that with the increasing of the probability that online seller providing high-quality green product, the evolutionary stable strategy of third-party e-commerce platform will change from SI to NSI.

According to Proposition 2, the third-party e-commerce platform's strategic choices are shown in **Figure 3**. Let V_{p1} represent the probability that third-party e-commerce platform chooses the SI strategy and V_{p2} represent the probability that third-party e-commerce platform chooses the NSI strategy.

$$V_{p1} = \int_0^1 \int_0^{1-\frac{C_{ph}-C_{pl}-J-P}{R_p+N_p+qF_p-V_p}} \left[1 - \frac{C_{ph} - C_{pl}}{P + J + (1 - x)\left(R_p + N_p + qF_p - V_p\right)}\right] dxdy$$
$$= 1 - \frac{C_{ph} - C_{pl}}{R_p + N_p + qF_p - V_p}\left(1 + \ln\frac{P + J + R_p + N_p + qF_p - V_p}{C_{ph} - C_{pl}}\right) \quad (13)$$

$$V_{p2} = 1 - V_{p1} = \frac{C_{ph} - C_{pl}}{R_p + N_p + qF_p - V_p}\left(1 + \ln\frac{P + J + R_p + N_p + qF_p - V_p}{C_{ph} - C_{pl}}\right) \quad (14)$$

Corollary 2.1 With the increasing of the reputation value premium brought by the consumer's positive evaluation or the reputation loss brought by the consumer's negative evaluation, the probability that a third-party e-commerce platform chooses the SI strategy will increase.

Proof Take the first-order derivative of V_{p1} with respect to R_p and N_p yield

$$\frac{\partial V_{p1}}{\partial R_p} = \frac{C_{ph}-C_{pl}}{R_p+N_p+qF_p-V_p}\left(\frac{1+\ln\left(P+J+R_p+N_p+qF_p-V_p\right)/\left(C_{ph}-C_{pl}\right)}{R_p+N_p+qF_p-V_p} - \frac{1}{P+J+R_p+N_p+qF_p-V_p}\right) > 0,$$

$$\frac{\partial V_{p1}}{\partial N_p} = \frac{C_{ph}-C_{pl}}{R_p+N_p+qF_p-V_p}\left(\frac{1+\ln\left(P+J+R_p+N_p+qF_p-V_p\right)/\left(C_{ph}-C_{pl}\right)}{R_p+N_p+qF_p-V_p} - \frac{1}{P+J+R_p+N_p+qF_p-V_p}\right) > 0.$$ V_{p1} is positively related to R_p and N_p. The probability that third-party e-commerce platform chooses the SI strategy is positively related to the reputation value premium brought by the consumer's positive evaluation and the reputation loss brought by the consumer's negative evaluation.

Corollary 2.1 indicates that the consumer's evaluation has an influence on the third-party e-commerce platform's reputation, which will affect a third-party e-commerce platform's strategic choice. With the increase of the reputation value premium or the reputation loss that a consumer's evaluation brings to the third-party e-commerce platform, the probability that a third-party e-commerce platform chooses the SI strategy will increase. Therefore, in order to give full play to the role of consumer, we should extend the consumer evaluation channel and encourage the consumer to participate in the evaluation actively.

Corollary 2.2 Governmental supervision department increases the penalty can encourage third-party e-commerce platform to choose the SI strategy.

Proof Take the first-order derivative of V_{p1} with respect to F_p fields

$$\frac{\partial V_{p1}}{\partial F_p} = \frac{q\left(C_{ph}-C_{pl}\right)}{R_p+N_p+qF_p-V_p}\left(\frac{1+\ln\left(P+J+R_p+N_p+qF_p-V_p\right)/\left(C_{ph}-C_{pl}\right)}{R_p+N_p+qF_p-V_p} - \frac{1}{P+J+R_p+N_p+qF_p-V_p}\right) > 0.$$ V_{p1} is positively related to F_p. The probability that third-party e-commerce platform chooses the SI strategy is positively related to the penalty from the governmental supervision department.

Corollary 2.2 indicates that the governmental supervision department should increase the penalty, which can promote a third-party e-commerce platform to choose the SI strategy.

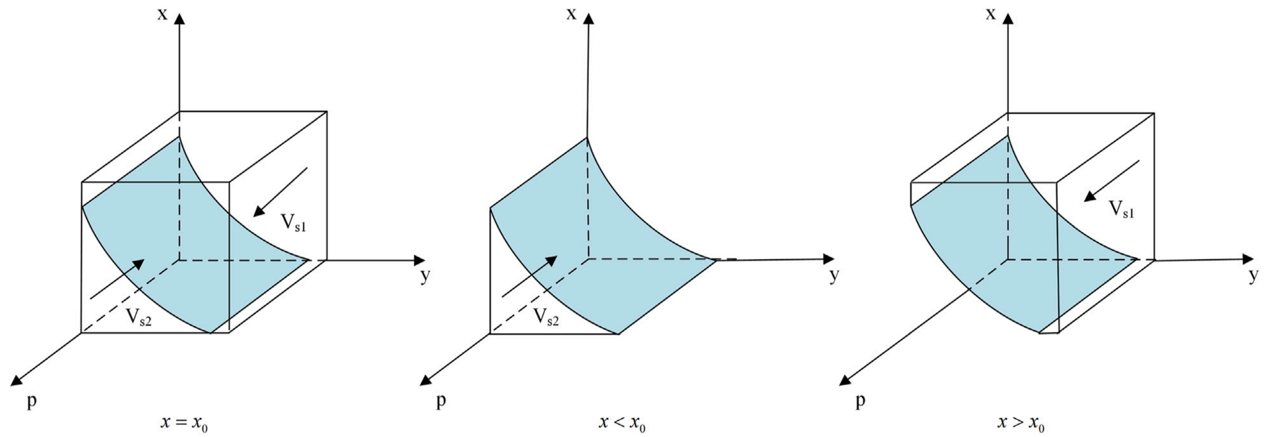

FIGURE 4 | The strategic choices of online seller.

The Stability Analysis of Online Seller Strategic Choices

The expected profit when an online seller chooses to provide high-quality green products isE_{PH}. The expected profit when an online seller chooses to provide low-quality green products is E_{PL}. The average expected profit of an online seller is $\overline{E_P}$. Replicator dynamic equation is $F(p)$ and its first-order derivative is $F'(p)$.

$$E_{PH} = y(V_s + R_s + J - C_{sh}) + (1-y)(V_s + R_s - C_{sh}) \tag{15}$$

$$E_{PL} = -C_{sl} - yP - (1-y)F_s[x + (1-x)q] + (1-x)(1-y)(V_s - N_s - qB_c) \tag{16}$$

$$\overline{E_P} = pE_{PH} + (1-p)E_{PL} \tag{17}$$

$$\begin{aligned} F(p) = dp/dt &= p\left(E_{PH} - \overline{E_P}\right) = p(1-p)(E_{PH} - E_{PL}) \\ &= p(1-p)\{V_s + R_s + y(J+P) + C_{sl} - C_{sh} + (1-y)F_s[x + (1-x)q] - (1-x)(1-y)(V_s - N_s - qB_c)\} \end{aligned} \tag{18}$$

$$F'(p) = (1-2p)\{V_s + R_s + y(J+P) + C_{sl} - C_{sh} + (1-y)F_s[x + (1-x)q] - (1-x)(1-y)(V_s - N_s - qB_c)\} \tag{19}$$

According to the stability theorem of differential equations, the probability of PH in a stable state must satisfy $F(p) = 0$ and $F'(p) < 0$.

Proposition 3 When $x < x_0$, the evolutionary stable strategy of the online seller is PL; when $x > x_0$, the evolutionary stable strategy of the online seller is PH; when $x = x_0$, there is no evolutionary stable strategy of the online seller. The threshold x_0 satisfies

$$x_0 = 1 - [y(J + P - F_s) + V_s + R_s + F_s + C_{sl} - C_{sh}]/[(1-y)(F_s + V_s - N_s - qF_s - qB_c)]$$

Proof Let $W(x) = V_s + R_s + y(J+P) + C_{sl} - C_{sh} - (1-x)(1-y)(V_s - N_s - qB_c) + (1-y)F_s[x + (1-x)q]$. Take the first-order derivative of $W(x)$ with respect to x yields $\partial W(x)/\partial x = (1-y)(1-q)F_s + (1-y)(V_s - N_s - qB_c) > 0$. That is, $W(x)$is positively related to x. When $x < x_0$, $W(x) < 0$, $F(p)\big|_{p=0} = 0$ and $F'(p)\big|_{p=0} < 0$, then $p = 0$ is evolutionary stable strategy. When $x > x_0$, $W(x) > 0$, $F(p)\big|_{p=1} = 0$ and $F'(p)\big|_{p=1} < 0$, then $p = 1$ is evolutionary stable strategy. When $x = x_0$, $W(x) = 0$, $F(p) = 0$ and $F'(p) = 0$, no evolutionary stable strategy.

Proposition 3 shows that with the increasing of a governmental supervision department's strict supervision probability, the evolutionary stable strategy of the online seller will change from PL to PH.

According to Proposition 3, the online seller's strategic choices are shown in **Figure 4**.

Let V_{s1} represent the probability that the online seller chooses the PH strategy, and V_{s2} represent the probability that the online seller chooses the PL strategy.

$$\begin{aligned} V_{s2} &= \int_0^1 \int_0^{\frac{C_{sh} - R_s - N_s - C_{sl} - qF_s - qB_c}{V_s + J + P - N_s - qF_s - qB_c}} \left[1 - \frac{y(J + P - F_s) + V_s + R_s + F_s + C_{sl} - C_{sh}}{(1-y)(F_s + V_s - N_s - qF_s - qB_c)}\right] dydp \\ &= 1 + \frac{J + P - F_s}{F_s + V_s - N_s - qF_s - qB_c} - \frac{V_s + R_s + J + P + C_{sl} - C_{sh}}{F_s + V_s - N_s - qF_s - qB_c} \ln \frac{V_s + J + P - N_s - qF_s - qB_c}{V_s + R_s + J + P + C_{sl} - C_{sh}} \end{aligned} \tag{20}$$

$$\begin{aligned} V_{s1} &= 1 - V_{s2} \\ &= \frac{V_s + R_s + J + P + C_{sl} - C_{sh}}{F_s + V_s - N_s - qF_s - qB_c} \ln \frac{V_s + J + P - N_s - qF_s - qB_c}{V_s + R_s + J + P + C_{sl} - C_{sh}} - \frac{J + P - F_s}{F_s + V_s - N_s - qF_s - qB_c} \end{aligned} \tag{21}$$

Corollary 3.1 With the increasing reward and penalty from a third-party e-commerce platform, the probability that the online seller chooses the PH strategy will increase.

Proof Take the first-order derivative of V_{s1} with respect to J and P yield

$$\frac{\partial V_{s1}}{\partial J} = \frac{\left[\ln \frac{V_s+J+P-N_s-qF_s-qB_c}{V_s+R_s+J+P+C_{sl}-C_{sh}} - 1 - \frac{(V_s+R_s+J+P+C_{sl}-C_{sh})(C_{sh}-C_{sl}-R_s-N_s-qF_s-qB_c)}{V_s+J+P-N_s-qF_s-qB_c}\right]}{F_s+V_s-N_s-qF_s-qB_c} > 0$$

$$\frac{\partial V_{s1}}{\partial P} = \frac{\left[\ln \frac{V_s+P+J-N_s-qF_s-qB_c}{V_s+R_s+P+J+C_{sl}-C_{sh}} - 1 - \frac{(V_s+R_s+P+J+C_{sl}-C_{sh})(C_{sh}-C_{sl}-R_s-N_s-qF_s-qB_c)}{V_s+P+J-N_s-qF_s-qB_c}\right]}{F_s+V_s-N_s-qF_s-qB_c} > 0$$

V_{s1} is positively related to J and P. The probability that an online seller chooses the PH strategy is positively related to reward and penalty from the third-party e-commerce platform.

Corollary 3.1 indicates that a third-party e-commerce platform should strengthen inspection, give higher reward to the online seller who provides high-quality green products, and severely penalize the online seller who provides low-quality green products.

Corollary 3.2 The higher the reputation value premium brought by a consumer's positive evaluation and the reputation loss brought by a consumer's negative evaluation, the higher the probability that an online seller chooses the PH strategy.

Proof Take the first-order derivative of V_{s1} with respect to R_s and N_s yield

$$\frac{\partial V_{s1}}{\partial R_s} = \frac{1}{F_s+V_s-N_s-qF_s-qB_c}\left(\ln \frac{V_s+J+P-N_s-qF_s-qB_c}{V_s+R_s+J+P+C_{sl}-C_{sh}} - 1\right) > 0$$

$$\frac{\partial V_{s1}}{\partial N_s} = \frac{V_s+R_s+J+P+C_{sl}-C_{sh}}{(F_s+V_s-N_s-qF_s-qB_c)^2}\ln \frac{V_s+J+P-N_s-qF_s-qB_c}{V_s+R_s+J+P+C_{sl}-C_{sh}} - \frac{J+P-F_s}{(F_s+V_s-N_s-qF_s-qB_c)^2} - \frac{V_s+R_s+J+P+C_{sl}-C_{sh}}{(F_s+V_s-N_s-qF_s-qB_c)(V_s+J+P-N_s-qF_s-qB_c)} > 0$$

V_{s1} is positively related to R_s and N_s. The probability that an online seller chooses the PH strategy is positively related to the reputation value premium and reputation loss brought by the consumer's evaluation.

Corollary 3.2 indicates that the consumer's evaluation will affect an online seller's reputation. After purchasing the green product, a consumer should actively make evaluation and promote the online seller to improve the green product quality.

Corollary 3.3 When the consumer purchased a low-quality green product, the higher compensation, the more an online seller tends to choose the PH strategy.

Proof Take the first-order derivative of V_{s1} with respect to B_c yields

$$\frac{\partial V_{s1}}{\partial B_c} = \frac{q(V_s+R_s+J+P+C_{sl}-C_{sh})}{(F_s+V_s-N_s-qF_s-qB_c)^2}\ln \frac{V_s+J+P-N_s-qF_s-qB_c}{V_s+R_s+J+P+C_{sl}-C_{sh}} - \frac{q(J+P-F_s)}{(F_s+V_s-N_s-qF_s-qB_c)^2} - \frac{q(V_s+R_s+J+P+C_{sl}-C_{sh})}{(F_s+V_s-N_s-qF_s-qB_c)(V_s+J+P-N_s-qF_s-qB_c)} > 0$$

V_{s1} is positively related to B_c. The probability that the online seller chooses the PH strategy is positively related to the compensation that the consumer gets.

Corollary 3.3 indicates that with the increasing of the compensation that the consumer gets, the probability that the online seller chooses the PH strategy will increase. Therefore, the governmental supervision department should improve the compensation and encourage consumers to complain after purchasing low-quality green products.

The Stability Analysis of Consumer Strategic Choices

The expected profit when a consumer chooses to complain is E_c. The expected profit when a consumer chooses not to complain is E_{NC}. The average expected profit of the consumer is $\overline{E_c}$. Replicator dynamic equation is $F(q)$, and its first-order derivative is $F'(q)$.

$$E_c = pR_c - x(1-p)N - (1-x)y(1-p)N + (1-x)(1-y)(1-p)(B_c - L_c - C_c) \quad (22)$$

$$E_{NC} = pR_c + (1-x)(1-y)(1-p)(-L_c) \quad (23)$$

$$\overline{E_c} = qE_c + (1-x)E_{NC} \quad (24)$$

$$F(q) = dq/dt = q\left(E_C - \overline{E_C}\right) = q(1-q)(E_C - E_{NC}) = q(1-q)[(1-x)(1-y)(1-p)(N + B_c - C_c) - (1-p)N] \quad (25)$$

$$F'(q) = (1-2q)[(1-x)(1-y)(1-p)(N + B_c - C_c) - (1-p)N] \quad (26)$$

According to the stability theorem of differential equations, the probability of C in a stable state must satisfy $F(q) = 0$ and $F'(q) < 0$.

Proposition 4 When $y < y_0$, the evolutionary stable strategy of consumer is C; when$y > y_0$, the evolutionary stable strategy of consumer is NC; when $y = y_0$, there is no evolutionary stable strategy of consumer. The threshold y_0 satisfies $y_0 = 1 - N/[(1-x)(N + B_c - C_c)]$.

Proof Let $Q(y) = (1-x)(1-y)(1-p)(N + B_c - C_c) - (1-p)N$. Take the first-order derivative of $Q(y)$with respect to y yields $\partial Q(y)/\partial y = -(1-x)(1-p)(N + B_c - C_c) < 0$. That is, $Q(y)$ is negatively related to y. When $y < y_0$, $Q(y) > 0$, $F(q)\big|_{q=1} = 0$ and $F'(q)\big|_{q=1} < 0$, then $q = 1$ is evolutionary stable strategy. When $y > y_0$, $Q(y) < 0$, $F(q)\big|_{q=0} = 0$ and $F'(q)\big|_{q=0} < 0$, then $q = 0$ is evolutionary stable strategy. When $y = y_0$, $Q(y) = 0$, $F(q) = 0$ and $F'(q) = 0$, there is no evolutionary stable strategy. Proposition 4 shows that with the increasing of the probability that third-party e-commerce platform choosing SI, the evolutionary stable strategy of the consumer will change from C to NC.

According to Proposition 4, a consumer's strategic choices are shown in **Figure 5**.

Let V_{q1} represent the probability that a consumer chooses the C strategy, and V_{q2} represent the probability that a consumer chooses the NC strategy.

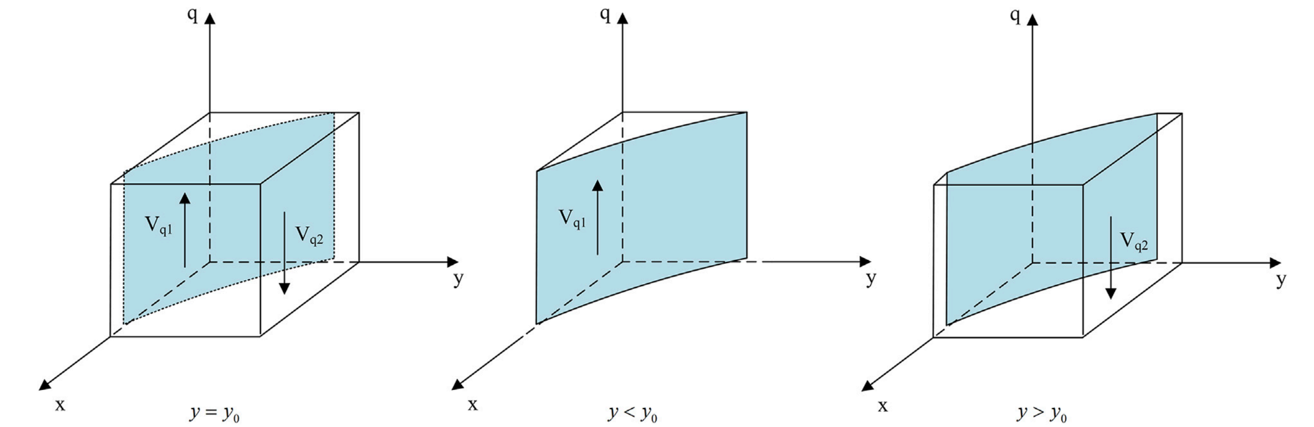

FIGURE 5 | The strategic choices of consumer.

$$V_{q1} = \int_0^1 \int_0^{N/(N+B_c-C_c)} [1 - N/[(1-x)(N+B_c-C_c)]]dxdq$$
$$= 1 - \frac{N}{N+B_c-C_c} + \frac{N}{N+B_c-C_c} \ln \frac{N}{N+B_c-C_c} \quad (27)$$

$$V_{q2} = 1 - V_{q1} = \frac{N}{N+B_c-C_c} - \frac{N}{N+B_c-C_c} \ln \frac{N}{N+B_c-C_c} \quad (28)$$

Corollary 4.1 With the increasing of a consumer's complaint cost, the probability that the consumer will choose the C strategy will decrease.

Proof Take the first-order derivative of V_{q1} with respect to C_c yields $\frac{\partial V_{q1}}{\partial C_c} = -\frac{N}{(N+B_c-C_c)^2} \ln \frac{N+B_c-C_c}{N} < 0$. V_{q1} is negatively related to C_c. The probability that the consumer choosing the C strategy is negatively related to the consumer's complaint cost.

Corollary 4.1 indicates that the consumer often gives up complaint because of the high cost, therefore, decreasing the complaint cost and simplifying the complaint process can encourage consumers to complain actively.

Corollary 4.2 When consumers purchase a low-quality green product, the higher compensation that consumers get from the online seller, the more consumers tend to choose the C strategy.

Proof Take the first-order derivative of V_{q1} with respect to B_c yields $\frac{\partial V_{q1}}{\partial B_c} = \frac{N}{(N+B_c-C_c)^2} \ln \frac{N+B_c-C_c}{N} > 0$. V_{q1} is positively related to B_c. The probability that a consumer chooses the C strategy is positively related to the compensation that a consumer gets from online sellers.

Corollary 4.2 indicates that the higher the compensation received from an online seller, the more the consumer is willing to protect rights through complaint.

STABILITY ANALYSIS OF STRATEGY COMBINATION

According to *Lyapunov's First Method*, if the Jacobi matrix eigenvalues are negative, the equilibrium solution is an evolutionary stable strategy (ESS); if the Jacobi matrix has one or more positive eigenvalues, the equilibrium solution is an unstable strategy; if the Jacobi matrix eigenvalues are zero or negative, the equilibrium solution's stability is uncertain. In a multi-party evolutionary game, if the equilibrium solution is an evolutionary stable strategy, the equilibrium solution is strict Nash equilibrium, that is, pure strategy equilibrium (Rong and Zhu, 2020). Therefore, this paper analyzes 16 pure strategy equilibrium solutions' stability. According to the four parties' replicator dynamic equations, we can get the following Jacobi matrix.

$$J = \begin{bmatrix} \partial F(x)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial p & \partial F(x)/\partial q \\ \partial F(y)/\partial x & \partial F(y)/\partial y & \partial F(y)/\partial p & \partial F(y)/\partial q \\ \partial F(p)/\partial x & \partial F(p)/\partial y & \partial F(p)/\partial p & \partial F(p)/\partial q \\ \partial F(q)/\partial x & \partial F(q)/\partial y & \partial F(q)/\partial p & \partial F(q)/\partial q \end{bmatrix} \quad (29)$$

Stability Analysis When Consumer Chooses Complaint

Consumer's evolutionary stable strategy is complaint, when $1 - y - N/[(1-x)(N+B_c-C_c)] > 0$ is satisfied. Substituting the pure strategy equilibrium solutions into the Jacobi matrix, we can get the eigenvalues, as shown in **Table 3**.

Proposition 5 When consumer chooses complaint, (0, 0, 1) is likely to become an only evolutionary stable strategy combination. At this time, the online seller chooses the PH strategy, third-party e-commerce platform chooses the NSI strategy, and the governmental supervision department chooses the LS strategy.

Proof According to the *Lyapunov's First Method*, when consumer chooses complaint, if condition $-(R_s + N_s + B_c + F_s + C_{sl} - C_{sh}) < 0$ is satisfied, the Jacobian matrix's eigenvalues of (0, 0, 1) are negative, therefore, (0, 0, 1) is an only evolutionary stable strategy combination. Proposition 5 shows that in order to promote an online seller to provide high-quality green products, the condition $-(R_s + N_s + B_c + F_s + C_{sl} - C_{sh}) < 0$ should be satisfied as much as possible. Therefore, the reputation value premium R_s brought by a consumer's positive evaluation and the reputation loss N_s brought by a consumer's negative evaluation, and the compensation B_c that a consumer gets from the online seller should be increased. Besides, the

TABLE 3 | Stability analysis when consumer chooses complaint.

Equilibrium point	Eigenvalues $\lambda_1, \lambda_2, \lambda_3$	Sign	Stability
(0,0,0)	$R_g - F_g - N_g - C_{gh}$,$R_p + N_p + F_p + P + C_{pl} - C_{ph} - V_p$,$R_s + N_s + B_c + F_s + C_{sl} - C_{sh}$	(−, +, ×)	Unstable
(1,0,0)	$-(R_g - F_g - N_g - C_{gh})$,$P + C_{pl} - C_{ph}$,$V_s + R_s + F_s + C_{sl} - C_{sh}$	(+, ×, ×)	Unstable
(0,1,0)	$-C_{gh}$,$-(R_p + N_p + F_p + P + C_{pl} - C_{ph} - V_p)$,$V_s + R_s + J + P + C_{sl} - C_{sh}$	(−, −, +)	Unstable
(0,0,1)	$-C_{gh}$,$C_{pl} - C_{ph} - J$,$-(R_s + N_s + B_c + F_s + C_{sl} - C_{sh})$	(−, −, ×)	When condition ① is satisfied, it is ESS
(1,1,0)	C_{gh},$-(P + C_{pl} - C_{ph})$,$V_s + R_s + J + P + C_{sl} - C_{sh}$	(+, ×, +)	Unstable
(1,0,1)	C_{gh},$C_{pl} - C_{ph} - J$,$-(V_s + R_s + F_s + C_{sl} - C_{sh})$	(+, −, ×)	Unstable
(0,1,1)	$-C_{gh}$,$-(C_{pl} - C_{ph} - J)$,$-(V_s + R_s + J + P + C_{sl} - C_{sh})$	(−, +, −)	Unstable
(1,1,1)	C_{gh},$-(C_{pl} - C_{ph} - J)$,$-(V_s + R_s + J + P + C_{sl} - C_{sh})$	(+, +, −)	Unstable

Note: × means the sign is uncertain. Condition①: $-(R_s + N_s + B_c + F_s + C_{sl} - C_{sh}) < 0$.

TABLE 4 | Stability analysis when consumer chooses no complaint.

Equilibrium point	Eigenvalues $\lambda_1, \lambda_2, \lambda_3$	Sign	Stability
(0,0,0)	$R_g - N_g - C_{gh}$,$R_p + N_p + P + C_{pl} - C_{ph} - V_p$,$R_s + N_s + C_{sl} - C_{sh}$	(+, +, ×)	Unstable
(1,0,0)	$-(R_g - N_g - C_{gh})$,$R_p + P - C_{ph}$,$V_s + R_s + F_s + C_{sl} - C_{sh}$	(−, ×, ×)	When condition ② is satisfied, it is ESS
(0,1,0)	$-C_{gh}$,$-(R_p + N_p + P + C_{pl} - C_{ph} - V_p)$,$V_s + R_s + J + P + C_{sl} - C_{sh}$	(−, −, +)	Unstable
(0,0,1)	$-C_{gh}$,$C_{pl} - C_{ph} - J$,$-(R_s + N_s + C_{sl} - C_{sh})$	(−, −, ×)	When condition ③ is satisfied, it is ESS
(1,1,0)	C_{gh},$-(P + C_{pl} - C_{ph})$,$V_s + R_s + J + P + C_{sl} - C_{sh}$	(+, ×, +)	Unstable
(1,0,1)	C_{gh},$C_{pl} - C_{ph} - J$,$-(V_s + R_s + F_s + C_{sl} - C_{sh})$	(+, −, ×)	Unstable
(0,1,1)	$-C_{gh}$,$-(C_{pl} - C_{ph} - J)$,$-(V_s + R_s + J + P + C_{sl} - C_{sh})$	(−, +, −)	Unstable
(1,1,1)	C_{gh},$-(C_{pl} - C_{ph} - J)$,$-(V_s + R_s + J + P + C_{sl} - C_{sh})$	(+, +, −)	Unstable

Note: × means the sign is uncertain. Condition②: $R_p + P - C_{ph} < 0$, $V_s + R_s + F_s + C_{sl} - C_{sh} < 0$. Condition③: $-(R_s + N_s + C_{sl} - C_{sh}) < 0$.

governmental supervision department should increase the penalty F_s for the online seller. In general, we should improve consumer evaluation and complaint channels, and the governmental supervision department should increase supervision and strictly punish illegal behavior.

Stability Analysis When Consumer Chooses No Complaint

Consumer chooses no complaint, when $1 - y - N/[(1 - x)(N + B_c - C_c)\ ] < 0$ is satisfied. Substituting the pure strategy equilibrium solutions into the Jacobi matrix, we can get the eigenvalues, as shown in **Table 4**.

Proposition 6 When a consumer chooses no complaint, (1, 0, 0) and (0, 0, 1) may become an evolutionary stable strategy combination.

Proof According to *Lyapunov's First Method*, when a consumer chooses no complaint, if conditions $R_p + P - C_{ph} < 0$, $V_s + R_s + F_s + C_{sl} - C_{sh} < 0$ are satisfied, the Jacobi matrix's eigenvalues of (1, 0, 0) are negative; if condition $-(R_s + N_s + C_{sl} - C_{sh}) < 0$ is satisfied, the Jacobi matrix's eigenvalues of (0, 0, 1) are negative. Therefore, (1, 0, 0) and (0, 0, 1) may become evolutionary stable strategy combination.

Proposition 6 shows that when a consumer chooses no complaint, the online seller may provide high-quality or low-quality green products. In order to promote an online seller to provide high-quality green quality, the condition $-(R_s + N_s + C_{sl} - C_{sh}) < 0$ should be satisfied as much as possible, the reputation value premium R_s for an online seller brought by the consumer's positive evaluation and the reputation loss N_s for online seller brought by consumer's negative evaluation should be increased. At the same time, in order to avoid (1, 0, 0) becoming an evolutionary stable strategy combination, the conditions $R_p + P - C_{ph} < 0$, $V_s + R_s + F_s + C_{sl} - C_{sh} < 0$ should not be satisfied, the reputation value premium R_p for third-party e-commerce platform brought by consumer's positive evaluation should be increased, third-party e-commerce platform should increases the penalty P for online seller, and governmental supervision department should also increases the penalty F_s for online seller.

NUMERICAL SIMULATION ANALYSIS

In this paper, we conduct numerical simulation by *Matlab 2020b*, which analyzes each factor how to influence the four parties' strategic choices. When assigning values to the parameters, we refer to the literature in some excellent journals and some statistics report data. According to consumer complaints, the *China Consumers Association* recovered a total of CNY 1.177 billion economic losses for consumers in 2019, and complaints about product quality problems accounted for 25.13% of all complaints. Therefore, this paper sets consumers' compensation B_c from online sellers as CNY 0.296 (25.13%*1.177) billion. According to *Statistical Bulletin of National Economic and Social Development in 2019*, physical products' annual online retail sales accounted for 20.7% of the total consumer products retail sales. Chinese Administration for Market Regulation's *2019 Departmental Budget* shows that the expenditure budget for market

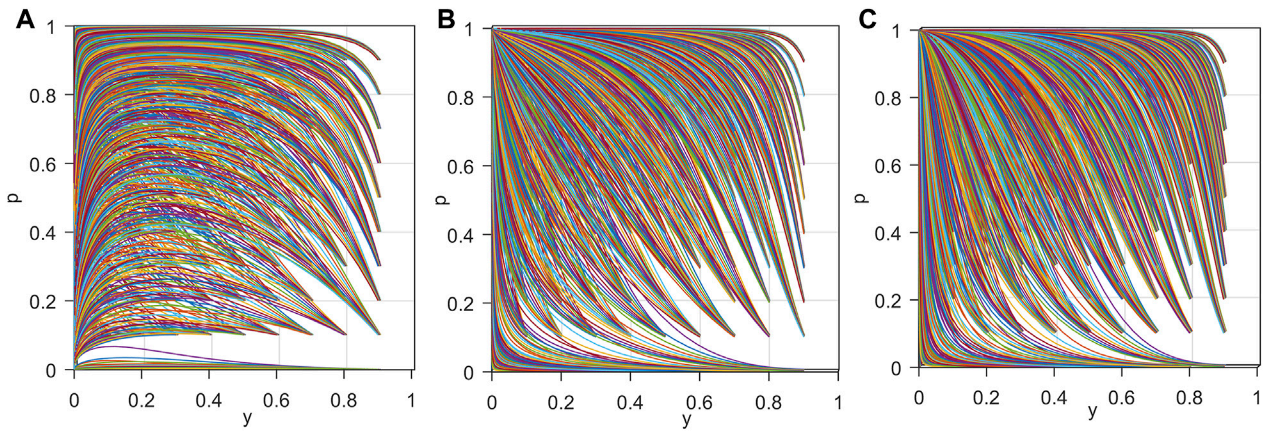

FIGURE 6 | The impact of reputation value premium and reputation loss. **(A)** when the situation is (0, 0). **(B)** when the situation is (4, 3). **(C)** when the situation is (8, 6).

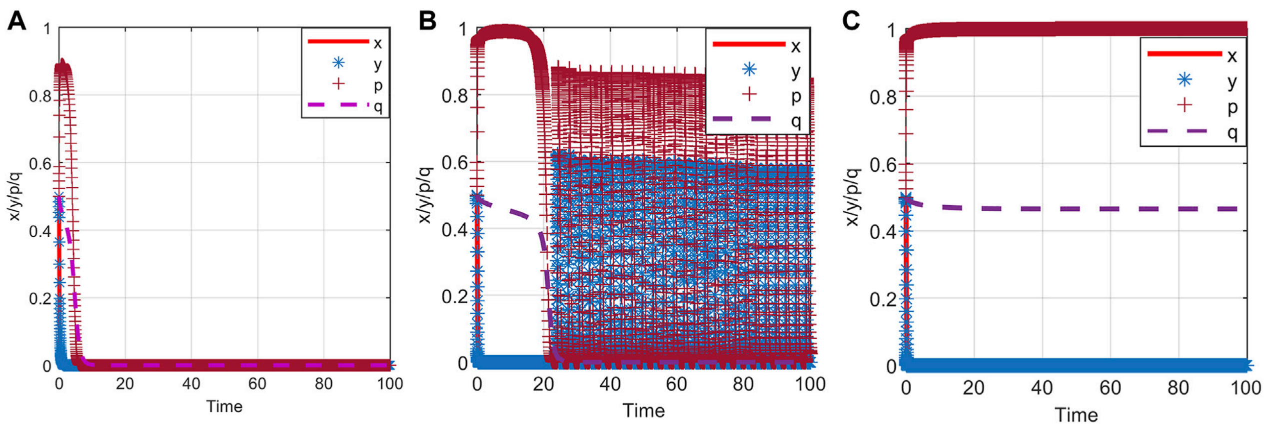

FIGURE 7 | The impact of reward and penalty. **(A)** when the situation is (0, 0). **(B)** when the situation is (30, 30). **(C)** when the situation is (60, 60).

supervision and management affairs is CNY 5.104 billion and the revenue budget is CNY 5.127 billion. Therefore, this paper sets the strict supervision cost C_{gh} by governmental supervision departments as CNY 1.057 (20.7% *5.104) billion, and third-party e-commerce platforms' penalty cost F_p as CNY 1.061 (20.7% *5.127) billion. Let each party's initial strategic choice be$\{0.5, 0.5, 0.5, 0.5\}$. The values of the other factors are as follows: $C_{ph} = 16$, $C_{pl} = 4$, $C_{sh} = 12$, $C_{sl} = 8$, $V_s = 20$, $V_p = 26$, $R_c = 4$, $L_c = 2$, $C_c = 4$, $N = 2$, $J = 4$, $P = 4$, $R_g = 4$, $N_g = 3$, $F_g = 8$, $F_s = 8$.

The Impact of Reputation Value Premium and Reputation Loss

Let $R_p = R_s = \{0, 4, 8\}$, $N_p = N_s = \{0, 3, 6\}$. The strategic choice and evolution process of third-party e-commerce platform and online seller are shown in **Figure 6**.

As can be seen from **Figure 6A**, when the reputation value premium or reputation loss brought by consumer evaluation are small, the stable point is (0,0). The online seller is stable in providing a low-quality green product, and a third-party e-commerce platform is stable in not strengthening inspection. But, with the increasing of reputation value premium or reputation loss, the greater the influence on the online seller and third-party e-commerce platform, the stable point turns into (0,1). The online seller's evolutionary stable strategy is to provide high-quality green product, and a third-party e-commerce platform's evolutionary stable strategy is not to strengthen inspection (**Figures 6B,C**). We can get that the increase in reputation value premium or reputation loss can promote the online seller to provide a high-quality green product.

The Impact of Reward and Penalty

Let $R_p = R_s = 4$, $N_p = N_s = 3$, $C_{ph} = 6$, $C_{pl} = 2$, $V_s = 12$. We change the online seller's reward and penalty from a third-

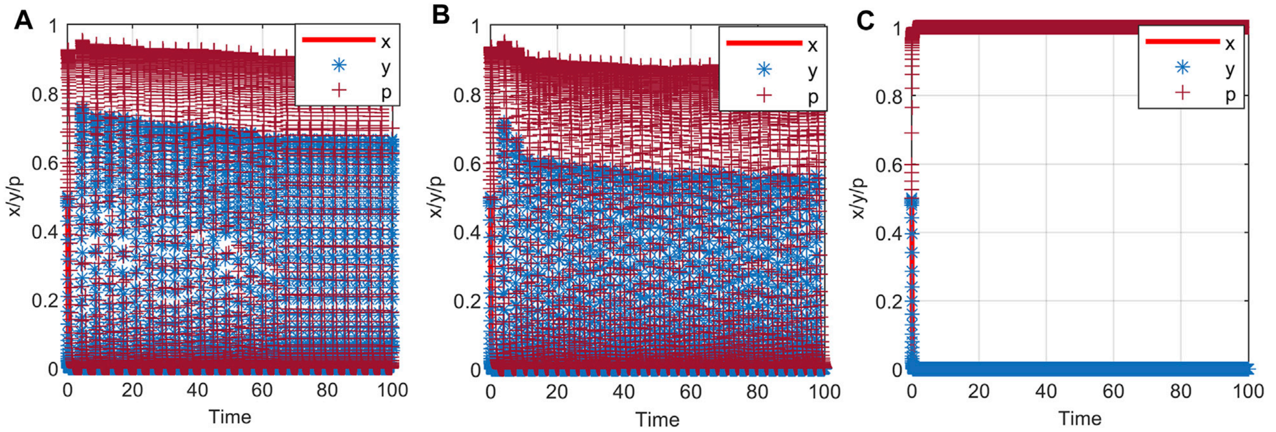

FIGURE 8 | The impact of consumer complaint. **(A)** when the situation is (0). **(B)** when the situation is (0.5). **(C)** when the situation is (1).

party e-commerce platform, and let$J = \{0, 30, 60\}$, $P = \{0, 30, 60\}$, then the strategic choice and evolution process of the four parties are shown in **Figure 7**.

As can be seen from **Figure 7A**, when an online seller's reward and penalty from third-party e-commerce platform is zero, it means that the third-party e-commerce platform has chosen not to strengthen inspection. At this time, $p = 0$, an online seller provides low-quality green products. However, with increasing of the reward and penalty, the online seller's strategic choice fluctuates, and a third-party e-commerce platform adjusts accordingly. Finally, $p = 1$, the online seller has gradually stabilized to provide high-quality green products, at this time, a third-party e-commerce platform has gradually stabilized to not strengthen inspection. This fully shows that the third-party e-commerce platform should give an online seller the higher reward or penalty, which can encourage the online seller to improve the green product quality.

The Impact of Consumer Complaint

Let $R_p = R_s = 4, N_p = N_s = 3, C_{ph} = 6, C_{pl} = 2, V_s = 12, J = P = 4$. We change the probability that a consumer chooses complaint, and let $q = \{0, 0.5, 1\}$. Then the strategic choice and evolution process of the four parties are shown in **Figure 8**.

As can be seen from **Figure 8**, when the probability that a consumer chooses complaint is low (**Figure 8A**), there is no evolutionary stable strategy. With the increasing of the probability that a consumer chooses complaint, the strategic choices of online seller and third-party e-commerce platform fluctuates (**Figure 8B**). When a consumer's strategic choice has gradually stabilized to choose complaint, the online seller will provide high-quality green products, and the third-party e-commerce platform will stabilize to not strengthen inspection (**Figure 8C**). Therefore, the consumer should raise rights protection awareness and actively complain about the online seller's illegal behavior.

The Impact of Penalty Cost

Let $R_p = R_s = 4, N_p = N_s = 3, C_{ph} = 6, C_{pl} = 2, V_s = 12, J = P = 4$, $q = 0.5$. We change the penalty cost, and let $F_g = \{6, 12, 18\}$, $F_p = \{4.61, 10.61, 16.61\}$, $F_s = \{2, 8, 14\}$. Then the strategic choice and evolution process of the four parties are shown in **Figure 9**.

As can be seen from **Figure 9**, when the penalty cost is low, the stable point is (0,0,0), governmental supervision department chooses to loosely supervise, third-party e-commerce platform chooses to strengthen inspection, and online seller chooses to provide low-quality green product (**Figures 9A,B**). With the increasing of the penalty cost, the stable point turns into (0,0,1), governmental supervision department has stabilized to loosely supervise, the third-party e-commerce platform has stabilized to not strengthen inspection, and the online seller has gradually stabilized to provide high-quality green product. Therefore, a governmental supervision department should increase the penalty to promote that the online seller provide high-quality green product.

SUMMARY

Conclusion and Policy Implications

This study describes that with the rapid e-commerce development, consumers pay more attention to sustainability, and a growing number of consumers prefer to purchase green products online. This paper considers consumer feedback mechanisms including evaluation and complaint and constructs four-party evolutionary game model, which analyzes four parties' evolutionary stable strategies. Further, it studies the conditions that make evolutionary stable strategy combination exist based on Lyapunov's First Method. Finally, this paper verifies theoretical analysis results with numerical simulation by Matlab 2020b. The main conclusions are as follows.

The consumer's evaluation will affect an online seller's reputation and promote the online seller to provide high-quality green product. When the reputation value premium or reputation loss brought by consumer evaluations are small,

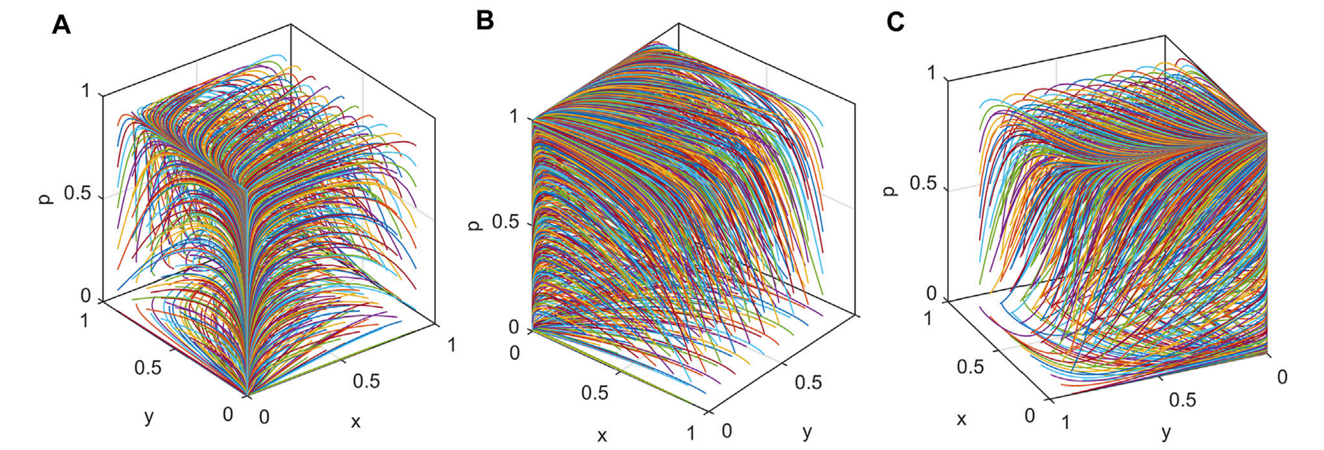

FIGURE 9 | The impact of penalty cost. **(A)** when the situation is (6, 4.61, 2). **(B)** when the situation is (12, 10.61, 8). **(C)** when the situation is (18, 16.61, 14).

the online seller is stable in providing low-quality green product. But, with the increasing of reputation value premium or reputation loss, the online seller's evolutionary stable strategy will turn into providing a high-quality green product. Therefore, third-party e-commerce platform should implement the reputation rating system based on consumer evaluation, which can be a constraint and incentive for online sellers, because it will directly affect the online seller's search rankings and promotion positions. And when the online seller provides low-quality green product, the consumer should make a negative evaluation.

Third-party e-commerce platform increases reward and penalty for the online seller can help improve online shopping green product quality. When an online seller's reward and penalty from third-party e-commerce platform are small, the online seller will provide a low-quality green product. However, with increasing of the reward and penalty, the online seller has gradually stabilized to provide high-quality green product. Therefore, the third-party e-commerce platforms should require the online seller to pay deposits. When an online seller harms the consumer rights, third-party e-commerce platforms can deduct the deposit as punishment for the online seller. Practice has proved that this method can indeed play an effective role in restraining the online seller's behavior.

Consumer complaints can urge an online seller to improve green product quality. With the increasing of the probability that a consumer is choosing complaint, the online seller will provide high-quality green product. Therefore, the governmental supervision department should improve the consumer complaint channel. The consumer should actively raise awareness of rights protection and incentive to complain or report to a governmental supervision department when the online seller provides low-quality green product; at this time, the governmental supervision department will punish the online seller severely. The most important thing is that an online seller can take on social responsibilities, continue to innovate product, and provide the consumer with high-quality product (Abbas et al., 2020).

Limitation and Future Direction

This paper provides pathways and direction for future research. It emphasizes effective supervision strategies for online shopping green product quality and constructs a four-party evolutionary game model. The study applies a mathematical model approach in this research. It considers consumer feedback mechanism (evaluation and complaint, and analyze the evolutionary stable strategies) and examines the existence of an evolutionary condition based on *Lyapunov's First Method*. It offers proposals for how to design effective green product quality and its supervision strategies when existing online shopping.

Concerning the study limitations, forthcoming studies can examine different factors models in different regions and countries. They can use different questionnaires for different variables, filled, and seek feedback from different respondents to eliminate the impact of standard method deviations on research results. Future studies can examine large sample sizes with different factors to draw exciting results. Besides, in the future, this paper can expand the model from the following aspects. It can construct a dynamic game model under asymmetric information and consider the game order and analyze each party's strategic choice in the long-term repeated game.

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.

AUTHOR CONTRIBUTIONS

HH writes the manuscript and data analysis, SZ contributed in the revision, LZ revises the manuscript and solves the model.

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