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# Promotion strategies for environmentally friendly packaging: a stochastic differential game perspective

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## Abstract
With the evolution of the e-commerce and express delivery industry, the consumption of packaging materials is increasing rapidly. Many members of society encourage using environmentally friendly packaging. However, due to the attitude-behavior gap, i.e., expressing concerns about environmental issues does not necessarily lead to green consumption, promoting the use of green packaging remains a challenge. This paper considers a stochastic differential game between green packaging manufacturers and e-commerce platforms. The optimal promotion strategies are derived for scenarios involving cooperation as well as non-cooperation. In addition, a welfare allocation mechanism for attaining stable cooperation is also discussed under the bargaining model. Numerical simulations and a sensitivity analysis were conducted to demonstrate the results. This paper finds that the cooperation between manufacturers and platforms can expand the actual market demand and promote the consumption of green packaging. The proposed model provides an effective tool for manufacturers and platforms to devise optimal strategies for promoting the use of green packaging.

**Keywords** Consumers behavior · Green packaging · Supply chain management · Welfare allocation mechanism

## Introduction

With the evolution of the e-commerce and express delivery industry, the consumption of packaging materials is increasing rapidly. Tallentire and Steubing (2020) reported that Europe produces 73 million tons of packaging materials each year, including packaging paper, cardboard, and plastics. In China, the express delivery industry took more than 60 billion express orders in 2020, as reported by State Post Bureau. The COVID-19 pandemic also boosted online shopping due to the epidemic prevention policy (Mouratidis and Papagiannakis 2021). A study released by Smithers (2021), a provider of packaging industry reports, predicted that the global packaging market will be valued at $1.22 trillion in 2026. Packaging waste has become a considerable source of greenhouse gases, and soil and ocean pollution. (Shen et al. 2020) reported that each ton of plastic packing waste would release 790 kg of carbon into the atmosphere, or about 2.9 tons of $CO2$. Groh et al. (2019) showed plastic packaging contains 68 dangerous chemicals related to environmental hazards. The extensive use of express packaging puts tremendous pressure on the environment and therefore incentivizes the use of environmentally friendly packaging (EFP) (Geueke et al. 2018).

EFP is also known as "eco-friendly," "sustainable," and "green packaging" (Prakash and Pathak 2017). Steenis et al. (2017) defined sustainable packaging as "packaging that has a comparatively low environmental impact as measured by life-cycle assessment models." Han et al. (2018) defined sustainable or green packaging from three levels: raw materials, production processes, and waste management. In general, EFP refers to packaging made from recyclable and degradable materials, which does not pollute the environment (Zhang and Zhao 2012; Wang and Hu 2016).

Although the use of EFP benefits the environment, the promotion of EFP still requires serious efforts. With the progress of society, people's awareness of environmental

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protection is growing. More and more consumers advocate green products (Asif et al. 2018), but consumer awareness of green products is only the first step in a buying decision process. Concerns about environmental issues do not necessarily lead to green consumption (Ramayah et al. 2010). This is a well-known phenomenon in the field of sustainable consumer behavior called the “attitude-behavior gap” (Park and Lin 2020) or “intention-behavior gap” (Frank and Brock 2018). Purchasing decisions are influenced by many factors, such as price, experience, lack of information, and perceived quality (Bray et al. 2011; Grunert 2011). Researchers found that few consumers are willing to pay more for an environmentally superior product, even when they claim to be environmentally conscious (Orsato 2006). As a result, how to promote the use of EFP is still a challenge.

This paper considers the strategies for promoting EFP from the perspectives of EFP manufacturers and e-commerce platforms. Manufacturers may determine their investments in research and development to improve the quality of EFP. Higher product quality increases the willingness of consumers to pay for EFP (Popovic et al. 2019). As the major consumers of packaging materials, e-commerce platforms, e.g., Amazon, Alibaba, and JD.com, are responsible for promoting the use of EFP (Escursell et al. 2021). Through investments in advertisements, e-commerce platforms can guide consumer behaviors and expand the potential market for EFP. This paper considers a stochastic differential game between EFP manufacturers and e-commerce platforms. It is the first time that the stochastic differential game has been introduced into the supply chain management of EFP. The paper aims to answer three questions:

(1) How to model the attitude-behavior gap in green consumption?
(2) What are the optimal promotion strategies for EFP manufacturers and e-commerce platforms under the cooperation/non-cooperation scenario?
(3) How to design the welfare allocation mechanism for stable cooperation?

This paper shows that the cooperation between manufacturers and e-commerce platforms can expand the actual market demand and promote the consumption of EFP. A welfare allocation mechanism for stable cooperation is also discussed under the bargaining model. The proposed model provides an effective tool for manufacturers and e-commerce platforms to devise optimal promotion strategies. The promotion strategies can help to significantly reduce packaging waste. Numerical simulations and a sensitivity analysis were performed to demonstrate the results and illustrate the effect of each of the six parameters on the optimal strategies.

The paper is organized as follows. Section 2 introduces a stochastic differential game between EFP manufacturers and e-commerce platforms and proposes the optimal promotion strategies under cooperation and non-cooperation scenarios. A welfare allocation mechanism for attaining stable cooperation is also discussed under the bargaining model. Section 3 presents numerical simulations and a sensitivity analysis to demonstrate the results. Section 4 concludes the paper. The research was conducted between October 2020 and May 2022 in Jiangsu University.

## Materials and methods

### Stochastic differential game

The paper considers the heterogeneity of consumers to model the attitude-behavior gap in green consumption (Allenby and Rossi 1998; Lim et al. 2005). In this paper, consumers are divided into two types: environmentally friendly consumers and ordinary consumers. Let $W$ be the willingness of consumers to purchase EFP. Then,

$$W = v + \alpha R - p, \tag{1}$$

where $v$ is the basic willingness of consumers to pay for EFP, which is a random variable and follows the uniform distribution on [0, 1], $R$ denotes the research and development efforts made by manufacturers, $\alpha$ is the utility coefficient of investments in product quality and $p$ is the price at which e-commerce platforms sell EFP to consumers. Thus, consumers with basic willingness $v \ge p - \alpha R$, i.e., $W \ge 0$, would like to purchase EFP and can be viewed as environmentally friendly consumers (Farshbaf-Geranmayeh and Zaccour 2021). Otherwise, consumers with basic willingness $v < p - \alpha R$, i.e., $W < 0$, prefer ordinary packaging and can be viewed as ordinary consumers. Thus, the actual market demand for EFP is $D$,

$$D = S \cdot \Pr(W \ge 0) = S \cdot \Pr(v \ge p - \alpha R) = S(1 - p + \alpha R), \tag{2}$$

where $S$ is the total market potential of EFP.

Note that, the market potential of EFP can be expanded by the advertisements and promotional efforts of e-commerce platforms. However, the effects of advertisements decay over time $t$. Therefore, the total market potential is considered as a state variable $S_t$ dynamically (Zhang et al. 2013; El Ouardighi 2014),

$$\begin{cases} dS_t = [\beta A - \theta S_t]dt + \sigma S_t dB_t, \\ S_0 = s_0 \ge 0, \end{cases} \tag{3}$$

where $A$ represents the advertisements and promotional efforts made by e-commerce platforms, $\beta$ is the utility coefficient of investments in promotions, $\theta$ is the natural decay rate of the effects of promotions, $B_t$ denotes the Brownian motion and $\sigma$ is the volatility parameter. Equation 3 models a stochastic differential equation to characterize the uncertainty of $S_t$, which is influenced by several unpredictable factors (Athanassoglou and Xepapadeas 2012; Masoudi et al. 2016).

To improve the quality of products and expand the market, manufacturers and e-commerce platforms take the costs of research and advertisements, respectively. The cost functions of manufacturers and e-commerce platforms, $C_M$ and $C_E$, are modeled as quadratic functions (De Giovanni et al. 2016; Pnevmatikos et al. 2018),

$$C_M = \frac{1}{2}\mu_M R^2, \quad C_E = \frac{1}{2}\mu_E A^2, \tag{4}$$

where $\mu_M$ and $\mu_E$ are cost coefficients of manufacturers and e-commerce platforms, respectively.

Table 1 summarizes the notations for variables and parameters as follows.

## Cooperation

If EFP manufacturers and e-commerce platforms cooperate with each other, they may determine the investments needed to maximize the entire expected profits. The exchange of inside benefits can be ignored. Therefore, the decision-making problem becomes one to solve the following optimization:

$$\begin{aligned}\max_{R,A} \Pi^C &= \max_{R,A} E\left[\int_0^\infty e^{-\rho t} p D_t \mathrm{d}t - C_M - C_E\right] \\ &= \max_{R,A} \int_0^\infty e^{-\rho t} p E[S_t](1 - p + \alpha R)\mathrm{d}t - \frac{1}{2}\mu_M R^2 - \frac{1}{2}\mu_E A^2.\end{aligned} \tag{5}$$

**Proposition 1** *Let $S_t$ be a stochastic process satisfying Eq. 3. The expected value of $S_t$ can be solved explicitly as follows:*

$$E[S_t] = s_0 e^{-\theta t} - \frac{\beta A}{\theta}(e^{-\theta t} - 1), \tag{6}$$

*where $s_0$ is the market potential at initial time $t = 0$.*

*For the proofs of propositions, see the Appendix for more details. Then, the optimization problem in Eq. 5 is solved.*

**Proposition 2** *In the scenario of cooperation, EFP manufacturers and e-commerce platforms may make the optimal investments in research efforts $R^C$ and advertisement efforts $A^C$, respectively:*

$$\begin{aligned}R^C &= \frac{\mu_E p\alpha s_0 \rho^2(\theta+\rho) + p^2\alpha\beta^2(1-p)}{\mu_M\mu_E\rho^2(\theta+\rho)^2 - p^2\alpha^2\beta^2}, \\ A^C &= \frac{\mu_M\mu_E\beta p(1-p)\rho^2(\theta+\rho)^2 + \mu_E s_0\alpha^2\beta p^2\rho^2(\theta+\rho)}{\mu_M\mu_E^2\rho^3(\theta+\rho)^3 - p^2\alpha^2\beta^2\mu_E\rho(\theta+\rho)}.\end{aligned} \tag{7}$$

With the optimal investment and promotion strategies in Eq. 7, manufacturers and e-commerce platforms can maximize the entire expected profits. How should the profits between two parties be allocated to ensure stable and lasting cooperation? A welfare allocation mechanism under the bargaining model is discussed in Section 2.4. In Section 3, a sensitivity analysis illustrates the impacts of parameters on the optimal strategies and profits.

## Non-cooperation

If EFP manufacturers and e-commerce platforms can not reach an agreement for cooperation, each party maximizes its own profits. In this situation, assume that the revenues are assigned between manufacturers and e-commerce platforms at a fixed proportion $\epsilon$, where $\epsilon \in (0, 1)$ (Chintagunta and Jain 1992; Jørgensen and

**Table 1** Notations for Variables and Parameters

| Notation | Description |
|---|---|
| $p$ | The price at which e-commerce platforms sell EFP to consumers |
| $W$ | The willingness of consumers to pay for EFP |
| $v$ | The basic willingness of consumers to pay for EFP |
| $R$ | Investments in research and development made by manufacturers |
| $\alpha$ | The utility coefficient of investments in product quality |
| $A$ | Investments in advertisements and promotions made by e-commerce platforms |
| $\beta$ | The utility coefficient of investments in promotions |
| $S$ | The total market potential of EFP |
| $D$ | The actual market demand for EFP |
| $\sigma$ | The volatility parameter of the total market potential |
| $\theta$ | The natural decay rate of effects of promotions |
| $C_M, C_E$ | Costs of manufacturers and e-commerce platforms |
| $\mu_M, \mu_E$ | Cost coefficients of efforts made by manufacturers and e-commerce platforms |
| $\rho$ | The discount rate of profits over time |

Zaccour 2003). For example, $\epsilon = 0.8$ means manufacturers take 80% of revenues of EFP, and e-commerce platforms take the rest.

The expected profit functions of manufacturers and e-commerce platforms can then be written as follows, and each party maximizes its own profits:

$$\max_R \Pi_M^{NC} = \max_R \ \epsilon \int_0^\infty e^{-\rho t} pE[S_t](1 - p + \alpha R)\mathrm{d}t - \frac{1}{2}\mu_M R^2,$$
$$\max_A \Pi_E^{NC} = \max_A \ (1-\epsilon) \int_0^\infty e^{-\rho t} pE[S_t](1 - p + \alpha R)\mathrm{d}t - \frac{1}{2}\mu_E A^2. \tag{8}$$

To balance the profits between manufacturers and e-commerce platforms, the assignment proportion $\epsilon$ should satisfy the following equation:

$$\Pi_M^{NC} = \Pi_E^{NC}. \tag{9}$$

Therefore, the equilibrium solution under the scenarios of non-cooperation can be obtained in Proposition 3.

**Proposition 3** *In the scenario of non-cooperation, EFP manufacturers and e-commerce platforms may make the optimal investments in research efforts $R^{NC}$ and advertisement efforts $A^{NC}$, respectively:*

$$R^{NC} = \frac{\epsilon\mu_E p\alpha s_0 \rho^2(\theta+\rho) + \epsilon(1-\epsilon)p^2\alpha\beta^2(1-p)}{\mu_M\mu_E\rho^2(\theta+\rho)^2 - \epsilon(1-\epsilon)p^2\alpha^2\beta^2},$$
$$A^{NC} = \frac{(1-\epsilon)\mu_M\mu_E\beta p(1-p)\rho^2(\theta+\rho)^2 + \epsilon(1-\epsilon)\mu_E s_0\alpha^2\beta p^2\rho^2(\theta+\rho)}{\mu_M\mu_E^2\rho^3(\theta+\rho)^3 - \epsilon(1-\epsilon)p^2\alpha^2\beta^2\mu_E\rho(\theta+\rho)}, \tag{10}$$

*and the optimal assignment proportion $\epsilon^*$ is equal*

$$\epsilon^* = \frac{2p(1-p+\alpha R)(\rho s_0 + \beta A) + \rho(\theta+\rho)(\mu_M R^2 - \mu_E A^2)}{4p(1-p+\alpha R)(\rho s_0 + \beta A)}. \tag{11}$$

Eq. 10 shows that the optimal strategies $R^{NC}$ and $A^{NC}$ depend on the assignment proportion $\epsilon$, while the optimal assignment proportion $\epsilon^*$ depends on the promotion strategies $R$ and $A$. The two equations are coupled with each other, making it hard to solve them explicitly. An iterative algorithm is developed to solve the equations numerically, as can be seen in Algorithm 1.

**Algorithm 1** Iterative Algorithm for $R^{NC}$, $A^{NC}$ and $\epsilon^*$

1: Initialize $R^{(0)}$, $A^{(0)}$ and $\epsilon^{(0)}$.
2: **repeat**
3: Update $R^{(i+1)}$ and $A^{(i+1)}$ by substituting $\epsilon = \epsilon^{(i)}$ in Equation 10.
4: Update $\epsilon^{(i+1)}$ by substituting $R = R^{(i+1)}$ and $A = A^{(i+1)}$ in Equation 11.
5: **until** $\max\{|R^{(i+1)} - R^{(i)}|, |A^{(i+1)} - A^{(i)}|, |\epsilon^{(i+1)} - \epsilon^{(i)}|\} < \eta$, where $\eta > 0$ is a tiny value.
6: Obtain the equilibrium strategies $R^{NC}$, $A^{NC}$ and $\epsilon^*$ until convergence.

## Welfare allocation mechanism

The welfare allocation mechanism between EFP manufacturers and e-commerce platforms is used to guarantee stable and lasting cooperation. A robust welfare allocation mechanism can form the linchpin of the promotion strategies of EFP by eliminating instability in a cooperation alliance and supporting continuous cooperation. It should satisfy the conditions of both holistic rationality and individual rationality. Holistic rationality ensures that the overall welfare can be improved through cooperative alliance. Individual rationality requires that the benefits gained from cooperative strategies for two parties should be greater than those of non-cooperative strategies.

The bargaining model theory is introduced to meet the principles mentioned above (Rubinstein 1982). Assume that the proportion of profits that EFP manufacturers take in the cooperative case is $\gamma$, where $\gamma \in [0,1]$, and that e-commerce platforms take the rest $(1-\gamma)$. Therefore, individual rationality requires

$$\begin{cases} \gamma\Pi^C \geq \Pi_M^{NC}, \\ (1-\gamma)\Pi^C \geq \Pi_E^{NC}. \end{cases} \tag{12}$$

The general solution is $\gamma \in \left[\frac{\Pi_M^{NC}}{\Pi^C}, \frac{\Pi^C - \Pi_E^{NC}}{\Pi^C}\right]$, which is the critical interval of the portion $\gamma$. According to the Rubinstein bargaining model, the discount factors $\delta_M$, $\delta_E$ are extracted to compute the welfare allocation ratio $\gamma$, where $\delta_M$, $\delta_E \in [0,1]$ characterize the "patience level" and "bargaining power" of manufacturers and e-commerce platforms, respectively.

Because EFP materials flow downstream, manufacturers could dominate the bargaining process. According to the Rubinstein indefinite periodic bidding game on the interval $[\frac{\Pi_M^{NC}}{\Pi^C}, \frac{\Pi^C - \Pi_E^{NC}}{\Pi^C}]$ (Rubinstein 1982), the optimal allocation ratio can be solved as a refined Nash equilibrium:

$$\gamma^* = \frac{1-\delta_E}{1-\delta_E\delta_M}\left(\frac{\Pi^C - \Pi_E^{NC}}{\Pi^C} - \frac{\Pi_M^{NC}}{\Pi^C}\right) + \frac{\Pi_M^{NC}}{\Pi^C}. \tag{13}$$

Hence, the welfare of two parties under a robust dynamic allocation mechanism can be written as

$$\begin{cases} \Pi_M^C = \frac{1-\delta_E}{1-\delta_E\delta_M}[\Pi_C - (\Pi_E^{\mathrm{NC}} + \Pi_M^{\mathrm{NC}})] + \Pi_M^{\mathrm{NC}}, \\ \Pi_E^C = \frac{\delta_E(1-\delta_M)}{1-\delta_E\delta_M}[\Pi_C - (\Pi_E^{\mathrm{NC}} + \Pi_M^{\mathrm{NC}})] + \Pi_E^{\mathrm{NC}}. \end{cases} \tag{14}$$

## Results and discussion

Numerical simulations and a sensitivity analysis were performed to demonstrate the results. This provided insights into the influence of each parameter on the optimal strategies of manufacturers and e-commerce platforms. This paper focuses on the relationship among different parameters rather than specific values. The parameter values were initially set, as shown in Table 2, to illustrate the impacts on optimal strategies.

### Analysis of equilibrium state trajectories

The trajectories of the state variable $S_t$ in two scenarios were compared. Because the stochastic differential equations in Eq. 3 cannot be solved analytically, their evolution path is characterized by simulations (Prasad and Sethi 2004). According to Eq. 3, the stochastic differential equations of $S_t$ in two scenarios can be written in the discrete forms:

$$S_{t+\Delta} = S_t + (\beta A - \theta S_t)\Delta + \sigma\sqrt{S_t}\sqrt{\Delta}\cdot\xi_t, \tag{15}$$

where $\xi_t \sim N(0,1)$ are i.i.d random variables. The tiny time step is set as $\Delta = 0.01$. Then, the evolution path and expectation of $S_t$ can be simulated by R language, as shown in Fig. 1.

Figure 1 shows that the total market potential of EFP in the cooperation scenario is much higher than that in the non-cooperation scenario. This holds for all studies of simulations, which indicates that cooperation between manufacturers and e-commerce platforms benefits both parties in terms of expanding the total market potential. Without such cooperation, manufacturers and e-commerce platforms would be more likely to reduce investments for their own benefit. Moreover, variation in the total market is significantly affected by several unpredictable factors. The confidence interval is used to describe the variation range of the EFP market potential (Zwillinger 1998). At a 95% confidence level, the confidence interval of EFP market potential should be $(E[S_t] - 1.96\sqrt{\mathrm{Var}[S_t]}, E[S_t] + 1.96\sqrt{\mathrm{Var}[S_t]})$, where $E[S_t]$ and $\mathrm{Var}[S_t]$ denote the expectation and variance of $S_t$, respectively. Figure 2 depicts the confidence interval of the total market potential and shows how it helps to improve the predictive power of diagnostic tools for manufacturers and e-commerce platforms.

### Effects of assignment proportion on profits

The impact of assignment proportion parameter $\epsilon$ on the profits is illustrated when manufacturers and e-commerce platforms do not reach a non-cooperative contract of equal profits $\Pi_M^{\mathrm{NC}} = \Pi_E^{\mathrm{NC}}$. For any given assignment proportion

**Table 2** Parameter Setting

| $p$ | $\alpha$ | $\beta$ | $\theta$ | $\mu_M$ | $\mu_E$ | $\rho$ | $\sigma$ | $s_0$ |
|---|---|---|---|---|---|---|---|---|
| 0.8 | 0.9 | 0.7 | 0.04 | 1.3 | 1.1 | 0.9 | 0.9 | 1000 |

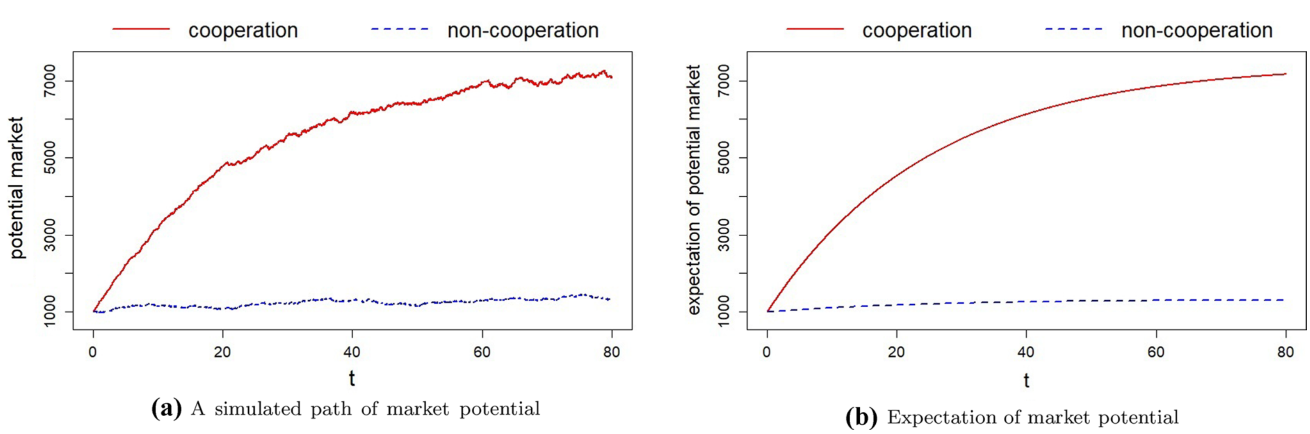
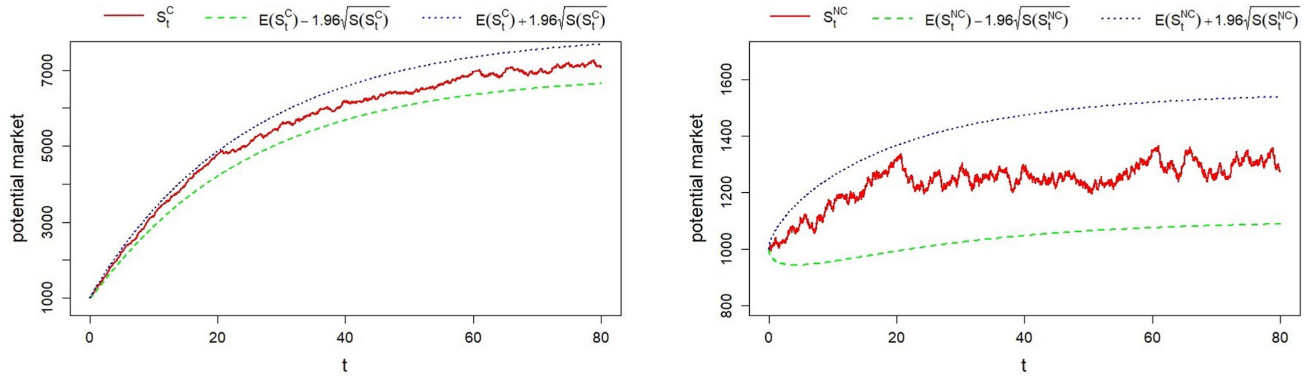



**Fig. 1** The evolution path of EFP total potential market $S_t$




**(a)** Cooperation **(b)** Non-cooperation

**Fig. 2** The confidence interval of EFP market potential under two scenarios

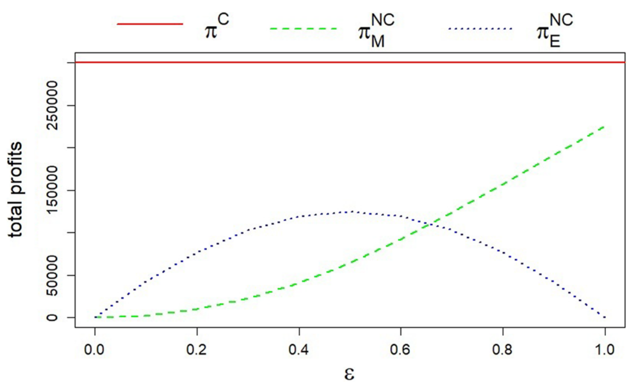



**Fig. 3** The profits of manufacturer and e-commerce platforms under different assignment proportions

$\epsilon$, Fig. 3 shows the profits of manufacturers and e-commerce platforms, respectively, in both cooperation and non-cooperation scenarios.

Figure 3 demonstrates that in the non-cooperation scenario, the profit of EFP manufacturers increases with the assignment proportion $\epsilon$ monotonically, whereas the profit of e-commerce platforms increases at the beginning and then decreases with the increase in $\epsilon$. The intersection of two curves illustrates the equilibrium state that $\Pi_M^{\mathrm{NC}} = \Pi_E^{\mathrm{NC}}$, which was discussed in Proposition 3.

Figure 3 also shows the leadership status of manufacturers in the supply chain of EFP production and promotion. If $\epsilon$ is small, manufacturers have no motivation to invest in and improve the quality of EFP. This results in few consumers choosing to pay for EFP, no matter how much e-commerce platforms promote it. With the increase in $\epsilon$, manufacturers obtain higher revenue shares and are therefore more willing to invest in the quality of EFP. This improvement entices more consumers to pay for EFP, thereby expanding the actual market potential. Because EFP manufacturers benefit from both factors, their profits increase monotonically with $\epsilon$. E-commerce platforms benefit from the gain of the actual market potential when $\epsilon$ is increasing. However, as revenue shares go down, they reduce their the investments in promotions.

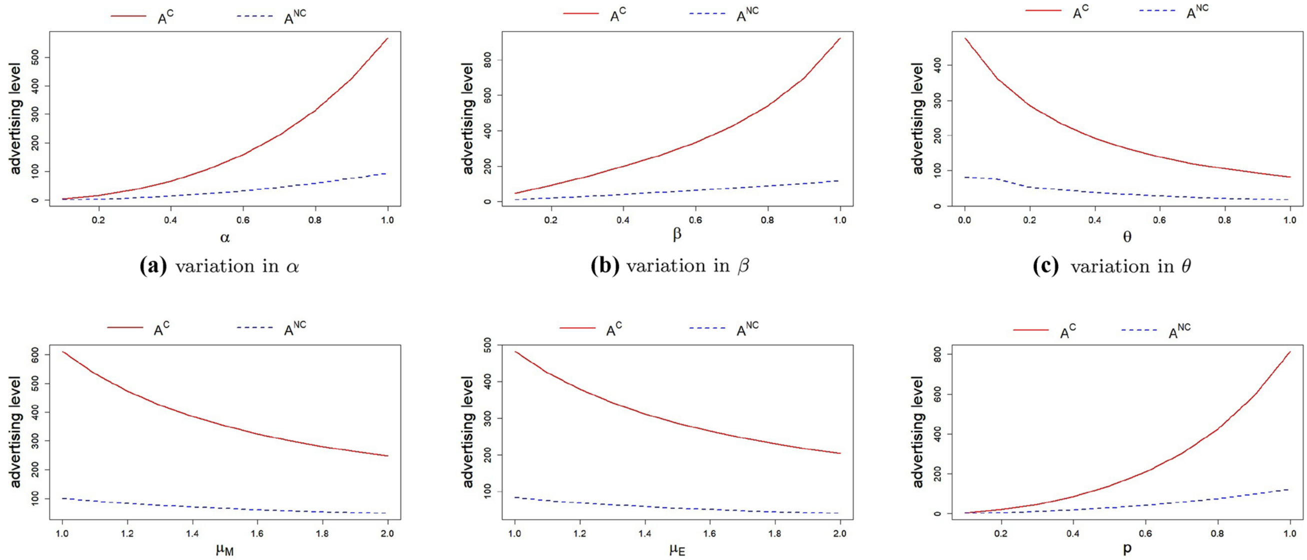
Therefore, to balance the interests of both sides, manufacturers and e-commerce platforms bargain and negotiate with each other in the long term. The equilibrium state $\Pi_M^{\mathrm{NC}} = \Pi_E^{\mathrm{NC}}$ is a point that both sides can accept. In the simulation setting, the equilibrium state is $\epsilon = 0.66$, which matches the numerical result solved by Algorithm 1.

## Sensitivity analysis

A sensitivity analysis was performed to explore the effects of parameters on the optimal strategies, such as advertising investments, research investments, and the corresponding profits of manufacturers and e-commerce platforms. This paper considers six parameters, namely the cost coefficients $(\mu_M, \mu_E)$, the decay rate of promotion $(\theta)$, the marginal utility of the EFP $(\alpha, \beta)$, and the selling price $(p)$. The equilibrium states for different parameter settings are solved for the cooperation and non-cooperation scenarios. For non-cooperation scenarios, the assignment proportion $\epsilon$ is determined by the equilibrium constraint $\Pi_M^{\mathrm{NC}} = \Pi_E^{\mathrm{NC}}$.

Figures 4, 5, and 6 depict the effects of the six parameters on the advertising investments $A$, research investments $R$, and the corresponding profits $\Pi$, respectively. Cooperation and non-cooperation scenarios are compared in the three figures.

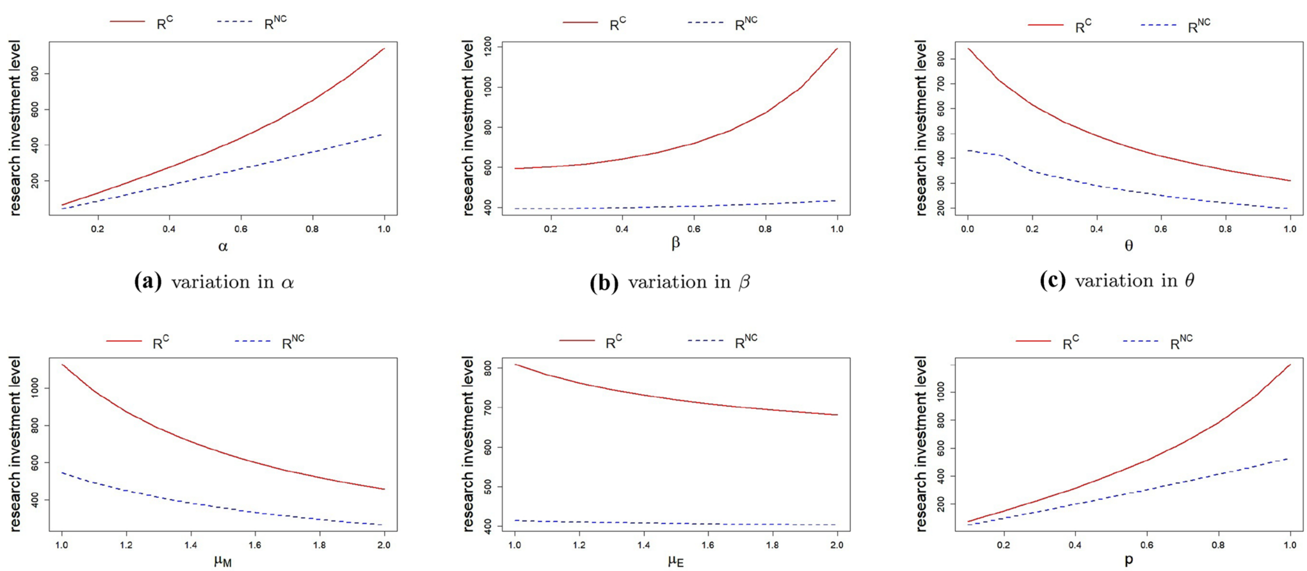
Figures 4, 5, and 6 show the variations in parameters cause similar trends in investment strategies and profits. $\alpha$ and $\beta$ denote the marginal utility of the EFP. Given that other parameters remain unchanged, higher $\alpha$ and $\beta$ mean larger market potential and more environmentally friendly consumers. It encourages manufacturers and e-commerce platforms to invest more in research and promotion. Manufacturers and e-commerce platforms also benefit from the higher selling price $p$, by gaining higher profits from EFP production. In




**(a)** variation in $\alpha$ **(b)** variation in $\beta$ **(c)** variation in $\theta$

**(d)** variation in $\mu_M$ **(e)** variation in $\mu_E$ **(f)** variation in $p$

**Fig. 4** Optimal advertising investments on the equilibrium states




**(a)** variation in $\alpha$ **(b)** variation in $\beta$ **(c)** variation in $\theta$

**(d)** variation in $\mu_M$ **(e)** variation in $\mu_E$ **(f)** variation in $p$

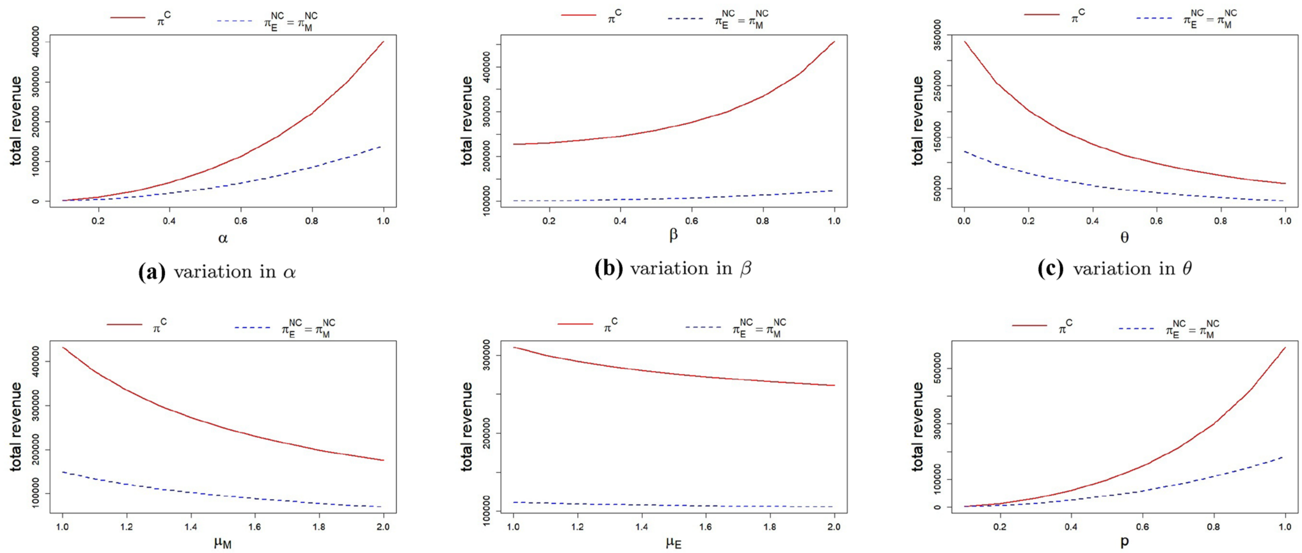
**Fig. 5** Optimal research investments on the equilibrium states

general, increased $\alpha$, $\beta$, and $p$ have positive effects on the optimal strategies.

However, the increase in cost coefficients $\mu_M$, $\mu_E$ and the decay rate of promotion $\theta$ discourage manufacturers and e-commerce platforms from investing in promotional activities. This means higher costs and lower effectiveness for both parties. Resultantly, they may reduce their budgets on investments, which would depress the EFP market. Therefore, increased $\mu_M$, $\mu_E$ and $\theta$ have negative effects on the optimal strategies.

Figs. 4, 5, and 6 further show that cooperation encourages manufacturers and e-commerce platforms to conduct more research and invest more in advertising than in the non-cooperation scenario. Manufacturers and e-commerce platforms both benefit from cooperation in all parameter settings and may gain higher profits than in the non-cooperation scenario.

The sensitivity analysis of parameters is summarized in Table 3. In the table, a + sign denotes the positive relationship, and a − sign denotes the negative relationship.




**(a)** variation in $\alpha$ **(b)** variation in $\beta$ **(c)** variation in $\theta$

**(d)** variation in $\mu_M$ **(e)** variation in $\mu_E$ **(f)** variation in $p$

**Fig. 6** Optimal profits on the equilibrium states

## Conclusion

This paper proposed a stochastic differential game for the promotion strategies of green packaging. The optimal investment strategies were derived from the perspectives of EFP manufacturers and e-commerce platforms. This paper introduced stochastic theory to capture the uncertainty of factors that affected the potential market, thereby creating a more real-world model. This was the first study to introduce the stochastic differential game into the supply chain management of EFP.

This paper showed that cooperation between EFP manufacturers and e-commerce platforms stimulated investments in product quality and promotion, thereby leading to higher profits and better environmental results in all of the parameter settings. Thus, manufacturers and platforms were motivated to cooperate. A welfare allocation mechanism for stable cooperation was also discussed. The optimal revenue assignment proportion was calculated for holistic rationality as well as individual rationality conditions. Through numerical simulations and a sensitivity analysis, this paper demonstrated the impacts of six parameters in the cooperation and non-cooperation scenarios. The results showed that the EFP market would benefit from higher utility coefficients and selling prices, but suffered when cost coefficients and the decay rate were increased.

Accordingly, a government can create several policies to promote the use of EFP. These include allowing additional tax deductions for research and development investments; reducing the cost coefficients of manufacturers to expand the EFP market; and offering a subsidy for the consumption of EFP, which would increase the consumer willingness to pay for EFP. This would thus reduce the amount of packaging waste.

Some interesting problems can be explored in the future, for example, the variation in consumer attitudes toward the cooperation between manufacturers and e-commerce platforms, and other factors affecting consumer behaviors except the selling price.

**Table 3** Sensitivity Analysis of Parameters

| Para | $A^C$ | $R^C$ | $\Pi^C$ | $A^{NC}$ | $R^{NC}$ | $\Pi^{NC}$ |
|---|---|---|---|---|---|---|
| $\alpha$ | + | + | + | + | + | + |
| $\beta$ | + | + | + | + | + | + |
| $\theta$ | − | − | − | − | − | − |
| $\mu_M$ | − | − | − | − | − | − |
| $\mu_E$ | − | − | − | − | − | − |
| $p$ | + | + | + | + | + | + |

## Appendix: Proofs of propositions

**Proposition 4** *By taking the expectation for both sides of Eq. 3, it leads to an ordinary differential equation with linear constant coefficients*:

$$\begin{cases} dE[S_t] = (\beta A - \theta E[S_t])dt, \\ S_0 = s_0. \end{cases}$$

Thus, it has the general solution

$$E[S_t] = Ce^{-\theta t} + \frac{\beta A}{\theta},$$

where $C$ is a undetermined coefficient. Since $S_0 = s_0$, it has

$$E[S_t] = s_0 e^{-\theta t} - \frac{\beta A}{\theta}(e^{-\theta t} - 1).$$

Proven.

**Proposition 5** *By taking the derivatives of $\Pi^C$ with respect to $R$, it has*

$$\begin{aligned} \frac{\partial \Pi^C}{\partial R} &= p\alpha \int_0^\infty e^{-\rho t}\left(s_0 e^{-\theta t} - \frac{\beta A}{\theta}(e^{-\theta t} - 1)\right)dt - \mu_M R \\ &= p\alpha\left(\frac{s_0 - \frac{\beta A}{\theta}}{\theta + \rho} + \frac{\frac{\beta A}{\theta}}{\rho}\right) - \mu_M R \\ &= \frac{p\alpha s_0}{\theta + \rho} + \frac{p\alpha\beta}{\rho(\theta + \rho)}A - \mu_M R. \end{aligned}$$

Similarly, by taking the derivatives of $\Pi^C$ with respect to $A$, it has

$$\begin{aligned} \frac{\partial \Pi^C}{\partial A} &= \int_0^\infty e^{-\rho t} p \frac{\beta}{\theta}(1 - e^{-\theta t})(1 - p + \alpha R)dt - \mu_E A \\ &= \frac{p\beta}{\theta}\frac{1}{\rho}(1 - p + \alpha R) - \frac{p\beta}{\theta}\frac{1}{\theta + \rho}(1 - p + \alpha R) - \mu_E A \\ &= \frac{p\beta(1 - p + \alpha R)}{\rho(\theta + \rho)} - \mu_E A. \end{aligned}$$

Then, the following equation system is solved to obtain the optima:

$$\begin{cases} \frac{p\alpha s_0}{\theta+\rho} + \frac{p\alpha\beta}{\rho(\theta+\rho)}A - \mu_M R = 0, \\ \frac{p\beta(1-p+\alpha R)}{\rho(\theta+\rho)} - \mu_E A = 0. \end{cases} \Rightarrow \begin{cases} R^C = \frac{\mu_E p\alpha s_0 \rho^2(\theta+\rho) + p^2\alpha\beta^2(1-p)}{\mu_M\mu_E\rho^2(\theta+\rho)^2 - p^2\alpha^2\beta^2}, \\ A^C = \frac{\mu_M\mu_E\beta p(1-p)\rho^2(\theta+\rho)^2 + \mu_E s_0\alpha^2\beta p^2\rho^2(\theta+\rho)}{\mu_M\mu_E^2\rho^3(\theta+\rho)^3 - p^2\alpha^2\beta^2\mu_E\rho(\theta+\rho)}. \end{cases}$$

Proven.

**Proposition 6** *By taking the derivatives of $\Pi^{NC}$ with respect to $R$, it has*

$$\begin{aligned} \frac{\partial \Pi^{NC}}{\partial R} &= \varepsilon p\alpha \int_0^\infty e^{-\rho t}\left(s_0 e^{-\theta t} - \frac{\beta A}{\theta}(e^{-\theta t} - 1)\right)dt - \mu_M R \\ &= \frac{\varepsilon p\alpha s_0}{\theta + \rho} + \frac{\varepsilon p\alpha\beta}{\rho(\theta + \rho)}A - \mu_M R. \end{aligned}$$

Similarly, by taking the derivatives of $\Pi^{NC}$ with respect to $A$, it has

$$\begin{aligned} \frac{\partial \Pi^{NC}}{\partial A} &= (1 - \varepsilon)p \int_0^\infty e^{-\rho t}\frac{\beta}{\theta}(1 - e^{-\theta t})(1 - p + \alpha R)dt - \mu_E A \\ &= (1 - \varepsilon)\frac{p\beta}{\theta}\frac{1}{\rho}(1 - p + \alpha R) \\ &\quad - (1 - \varepsilon)\frac{p\beta}{\theta}\frac{1}{\theta + \rho}(1 - p + \alpha R) - \mu_E A \\ &= \frac{(1 - \varepsilon)\varepsilon p\beta(1 - p + \alpha R)}{\rho(\theta + \rho)} - \mu_E A. \end{aligned}$$

According to Eq. 9, it has

$$\begin{aligned} &\epsilon \int_0^\infty e^{-\rho t} pE[S_t](1 - p + \alpha R)dt - \frac{1}{2}\mu_M R^2 \\ &\quad = (1 - \epsilon)\int_0^\infty e^{-\rho t} pE[S_t](1 - p + \alpha R)dt - \frac{1}{2}\mu_E A^2. \end{aligned}$$

Then, the following equation system is solved to obtain the optima:

$$\begin{cases} \frac{\epsilon p\alpha s_0}{\theta+\rho} + \frac{\epsilon p\alpha\beta}{\rho(\theta+\rho)}A - \mu_M R = 0, \\ \frac{(1-\epsilon)p\beta(1-p+\alpha R)}{\rho(\theta+\rho)} - \mu_E A = 0. \end{cases}$$

$$\Rightarrow \begin{cases} R^{NC} = \frac{\epsilon\mu_E p\alpha s_0\rho^2(\theta+\rho) + \epsilon(1-\epsilon)p^2\alpha\beta^2(1-p)}{\mu_M\mu_E\rho^2(\theta+\rho)^2 - \epsilon(1-\epsilon)p^2\alpha^2\beta^2}, \\ A^{NC} = \frac{(1-\epsilon)\mu_M\mu_E\beta p(1-p)\rho^2(\theta+\rho)^2 + \epsilon(1-\epsilon)\mu_E s_0\alpha^2\beta p^2\rho^2(\theta+\rho)}{\mu_M\mu_E^2\rho^3(\theta+\rho)^3 - \epsilon(1-\epsilon)p^2\alpha^2\beta^2\mu_E\rho(\theta+\rho)}, \end{cases}$$

and the optimal $\epsilon^*$ is equal

$$\epsilon^* = \frac{2p(1 - p + \alpha R)(\rho s_0 + \beta A) + \rho(\theta + \rho)(\mu_M R^2 - \mu_E A^2)}{4p(1 - p + \alpha R)(\rho s_0 + \beta A)}.$$

Proven.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

## References


Allenby GM, Rossi PE (1998) Marketing models of consumer heterogeneity. J Ecometrics 89(1–2):57–78

Asif M, Xuhui W, Nasiri A, Ayyub S (2018) Determinant factors influencing organic food purchase intention and the moderating role of awareness: a comparative analysis. Food Qual Prefer 63:144–150

Athanassoglou S, Xepapadeas A (2012) Pollution control with uncertain stock dynamics: when, and how, to be precautious. J Environ Econ Manag 63(3):304–320

Bray J, Johns N, Kilburn D (2011) An exploratory study into the factors impeding ethical consumption. J Bus Ethics 98(4):597–608

Chintagunta PK, Jain D (1992) A dynamic model of channel member strategies for marketing expenditures. Market Sci 11(2):168–188

De Giovanni P, Reddy PV, Zaccour G (2016) Incentive strategies for an optimal recovery program in a closed-loop supply chain. Eur J Oper Res 249(2):605–617

El Ouardighi F (2014) Supply quality management with optimal wholesale price and revenue sharing contracts: A two-stage game approach. Int J Prod EconInt J Prod Econ 156:260–268

Escursell S, Llorach-Massana P, Roncero MB (2021) Sustainability in e-commerce packaging: A review. J Clean Prod 280:124314

Farshbaf-Geranmayeh A, Zaccour G (2021) Pricing and advertising in a supply chain in the presence of strategic consumers. Omega 101:102239

Frank P, Brock C (2018) Bridging the intention-behavior gap among organic grocery customers: the crucial role of point-of-sale information. Psychol Market 35(8):586–602

Geueke B, Groh K, Muncke J (2018) Food packaging in the circular economy: overview of chemical safety aspects for commonly used materials. J Clean Prod 193:491–505

Groh KJ, Backhaus T, Carney-Almroth B, Geueke B, Inostroza PA, Lennquist A, Leslie HA, Maffini M, Slunge D, Trasande L et al (2019) Overview of known plastic packaging-associated chemicals and their hazards. Sci Total Environ 651:3253–3268

Grunert KG (2011) Sustainability in the food sector: a consumer behaviour perspective. Int J Food Syst Dyn 2(3):207–218

Han JW, Ruiz-Garcia L, Qian JP, Yang XT (2018) Food packaging: a comprehensive review and future trends. Compr Rev Food Sci F 17(4):860–877

Jørgensen S, Zaccour G (2003) A differential game of retailer promotions. Automatica 39(7):1145–1155

Lim J, Currim IS, Andrews RL (2005) Consumer heterogeneity in the longer-term effects of price promotions. Int J Res Mark 22(4):441–457

Masoudi N, Santugini M, Zaccour G (2016) A dynamic game of emissions pollution with uncertainty and learning. Environ Resour Econ 64(3):349–372

Mouratidis K, Papagiannakis A (2021) Covid-19, internet, and mobility: the rise of telework, telehealth, e-learning, and e-shopping. Sustain Cities Soc 74:103182

Orsato RJ (2006) Competitive environmental strategies: when does it pay to be green? Calif Manage Rev 48(2):127–143

Park HJ, Lin LM (2020) Exploring attitude-behavior gap in sustainable consumption: comparison of recycled and upcycled fashion products. J Bus Res 117:623–628

Pnevmatikos N, Vardar B, Zaccour G (2018) When should a retailer invest in brand advertising? Eur J Oper Res 267(2):754–764

Popovic I, Bossink BA, van der Sijde PC (2019) Factors influencing consumers’ decision to purchase food in environmentally friendly packaging: what do we know and where do we go from here? Sustainability 11(24):7197

Prakash G, Pathak P (2017) Intention to buy eco-friendly packaged products among young consumers of india: a study on developing nation. J Clean Prod 141:385–393

Prasad A, Sethi SP (2004) Competitive advertising under uncertainty: a stochastic differential game approach. J Optimiz Theory App 123(1):163–185

Ramayah T, Lee JWC, Mohamad O (2010) Green product purchase intention: some insights from a developing country. Resour Conserv Recyl 54(12):1419–1427

Rubinstein A (1982) Perfect equilibrium in a bargaining model. Econometrica pp 97–109

Shen M, Huang W, Chen M, Song B, Zeng G, Zhang Y (2020) (micro) plastic crisis: un-ignorable contribution to global greenhouse gas emissions and climate change. J Clean Prod 254:120138

Smithers (2021) The Future of Global Flexible Packaging to 2026

Steenis ND, van Herpen E, van der Lans IA, Ligthart TN, van Trijp HC (2017) Consumer response to packaging design: the role of packaging materials and graphics in sustainability perceptions and product evaluations. J Clean Prod 162:286–298

Tallentire C, Steubing B (2020) The environmental benefits of improving packaging waste collection in Europe. Waste Manag 103:426–436

Wang F, Hu Y (2016) Research on green express packaging design under the electronic commerce. Open J Bus Manag 04(4):621–628

Zhang G, Zhao Z (2012) Green packaging management of logistics enterprises. Phys Proc 24:900–905

Zhang J, Gou Q, Liang L, Huang Z (2013) Supply chain coordination through cooperative advertising with reference price effect. Omega 41(2):345–353

Zwillinger D (1998) Handbook of Differential Equations. Gulf Professional Publishing