Information Sharing in a Green Supply Chain with a Common Retailer

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ABSTRACT

In the paper, we analyze the problem of information sharing in a green supply chain with two competing manufacturers selling environmentally friendly substitutable products in markets through a common retailer. We develop a game-theoretic framework of a network supply chain structure. The study shows that (a) the manufacturer is better off while the retailer is worse off when the retailer shares his private information with the manufacturer; (b) the equilibrium greening levels are the highest when both the manufacturers are informed; (c) under intense competition, the retailer has an incentive to share the information with the manufacturer; (d) the equilibrium greening levels decrease with information inaccuracy. This study shows the existence of a contracting mechanism the manufacturers can employ to induce information sharing. This study's results will be helpful to managers of green supply chain structures to make marketing and operational decisions under uncertain situations. The main contribution of this study is that it explores the problem of information sharing in a green supply chain under competition.

KEYWORDS

Information Sharing, Green Supply Chain, Retailer, Supply Chain

INTRODUCTION

Many firms worldwide are making significant efforts to reduce carbon footprints in their supply chains and produce green products. For instance, IKEA has committed to using only renewable and recycled materials by 2030, Patagonia plans to achieve carbon neutrality by 2025 in its supply chains (Gao and Souza, 2022), and automobile companies are moving from gasoline vehicles to electric vehicles to reduce carbon emissions. Green products emit less emission during production, consumption, and end-of-life product than conventional products (Gopalakrishnan et al., 2020). Companies that produce green products in their supply chain are considered green supply chains (Gopalakrishnan et al., 2020; He et al., 2021). Companies like Unilever and Walmart face carbon emissions and negative environmental issues from their internal and suppliers' operations. In fact, in some of the cases, the suppliers contribute around 80 % of total emissions in the supply chain (Meinrenken et al., 2020). Thus, companies like Walmart, Tata Motors, and Patagonia have taken several steps to encourage suppliers to produce green products.

However, the manufacturers/suppliers incur costs to produce green products. For instance, in the case of electric vehicle production, which is the type of green product, the manufacturers would have to invest a one-time fixed cost to implement the technology. However, they are uncertain about the return on their investment from a adopting new technology (Gao and Leng, 2021). Further, the manufacturers make investment decisions and try to produce green products based on market

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demand and competition (Gao and Leng, 2021; Shang et al., 2016). Generally, retailers obtain rich and efficient market information due to their proximity to the market. The retailer could share the data directly or indirectly via third-party data service providers. But there are several issues in implementing the data-sharing agreement between the manufacturers and retailers. First, the retailers might be unwilling to share the data with the suppliers because they fear losing their information advantage. However, rich information allows the manufacturers to plan for better greening investments. Thus, the manufacturer may offer payments to the retailer to induce him to share private demand information regarding green products. However, these issues are unexplored in the context of the green supply chain.

Much work has been done in the supply chain literature to analyze the greening level decisions. There is also a wide range of literature regarding information sharing in the marketing and supply chain. However, very few papers considered information-sharing decisions in the green supply chain. We aim to fill this literature gap by addressing the following research questions: (a) How is the greening effort justified under uncertain demand? (b) How does competition on the manufacturers' side affect the greening decisions? (c) When does the retailer share the demand information with the manufacturers?

To address these research questions, this paper considers a green supply chain where two competing manufacturers produce and sell green products in markets through a common retailer. We use a game-theoretical model to study how competition and information sharing affect the manufacturers' decisions regarding their greening levels Our results suggest that information sharing benefits the manufacturers and leads to higher equilibrium greening levels. Intense competition on the manufacturers' side induces the retailer to voluntarily share information. The retailer is unwilling to share his demand information with the moderate and lower competition without any payment. In this case, we design a side payment to induce the retailer to share his information with the manufacturers. We also show that information sharing is more beneficial to the supply chain if the manufacturer is efficient in greening efforts.

RELATED LITERATURE REVIEW AND RESEARCH GAPS

This paper relates to three different streams of literature: (i) green supply chain, (ii) competition and (iii) information sharing. The details of each are discussed below:

GREEN SUPPLY CHAIN

The green supply chain is well-studied in the supply chain literature (Abbasi and Ahmadi Choukolaei, 2023; Srivastava, 2007). Different set of authors has considered different approaches including game theoretic approach (Adhikari and Bisi, 2020; Ghosh and Shah, 2015), case studies (Scur and Barbosa, 2017), empirical approach (Chen et al., 2022; Raj et al., 2020). This study is closely related to the game theoretic approach. Ghosh and Shah (2015) and Swami and Shah (2013) are one of the early papers that analyze a green supply chain where authors assume that only the manufacturer puts efforts into greening, further Swami and Shah (2013) consider the situation where both suppliers and manufacturer put efforts into greening. Subsequently, several authors extended these models by (a) considering carbon emission abatement efforts and government cap regulation wherein the government imposes some carbon emission (Darzi Ramandi and Khakzar Bafruei, 2020; Rout et al., 2020) (b) asymmetric information about supplier's cost (Raj et al., 2021) and (c) fairness concern (Adhikari and Bisi, 2020). Recently, Sharma et al. (2023) considered power structure in the green supply chain. However, within the game theoretic approach under a green supply chain, most studies consider deterministic demand and a dyadic supply chain without competition (Becerra et al., 2021).

COMPETITION

Some papers on the green supply chain consider oligopolistic models (Hafezalkotob, 2017; Jain and Hazra, 2020; Li et al., 2021). Hafezalkotob (2017) analyzes a competitive model for two green supply chains, and results suggest that appropriate tariff mechanisms could improve sustainability. Liu et al. (2012) developed a model that considers the quantity competition for green products and suggests that competition increases the retailer's profits. Recently Guo et al. (2020) analyzed a green supply chain model with one manufacturer and two retailers and analyze how retail competition impacts green product decisions. Jain and Hazra (2020) extend their model and analyze the green supply chain under competition under stochastic demand. However, unlike other studies, we consider a green supply chain model under demand information sharing in competing supply chains.

INFORMATION SHARING

Information sharing under demand uncertainty is well-studied in the literature (Chen et al., 2023; Guan et al., 2020; Jain et al., 2011; Shang et al., 2016; Li, 2002). These studies indicate that information sharing benefits the supply chain. Information sharing about demand uncertainty can be broadly categorized into three streams of research. The first stream of research considered vertical information sharing with the downstream competition (Zhang, 2002; Zhou et al., 2017). The second stream of research analyzed the competing supply chain model under information sharing (Guan et al., 2020; Ha et al., 2017, 2011). Ha et al. (2011, and Ha et al. (2017) analyzed two different supply chains, each consisting of one manufacturer and one retailer. These authors identify a condition under which vertical information sharing can be a win-win situation for both parties. The third stream of research is related to information sharing with upstream competition (Shang et al., 2016; Xu et al., 2023). Shang et al. (2016) consider a model with upstream competition and design a mechanism under which retailers would like to share the information with the manufacturer. The authors investigate conditions under which retailers would like to share the information with the manufacturer.

Our paper is closely related to the third stream of research. However, it is distinct from other studies because we investigate how information sharing impacts greening-level decisions. To the best of our knowledge, our study is one of the first papers to examine the greening level of products considering demand information sharing under upstream competition. We also design a payment scheme that incentivizes retailers to share their demand information with the manufacturers. Table 1 summarizes recent contextual research.

THE MODEL

We consider a supply chain that consists of two identical manufacturers (indexed by 1 and 2) selling substitutable green products through a common retailer. The demand function for product i is given by

$$q_i \quad = b + \alpha\theta_i + \epsilon - p_i + \lambda p_j \quad \text{for } j \neq i, i, j = 1,2 \tag{1}$$

In Equation (1) , b is a constant and represents market potential; p_i and q_i are the retail price and order quantity of retailer i, respectively; θ_i is the greening effort exerted by manufacturer i and considered as the greening level of the product (higher value of θ indicates a higher level of greening); α is the consumer sensitivity towards greening level; λ indicates the competition intensity (larger λ means more intense competition); and the random variable ϵ, with mean zero and variance σ^2, represents demand uncertainty. This type of linear demand function is commonly used in the supply

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Table 1. Summary of Relevant Literature

	Green Production Aspect	Supply Chain Structure	Competition	Information Sharing
Adhikari and Bisi (2020)	✓	*1M-1R*		
Guan et al. (2020)		*1M-1R,1M-1R*	✓	✓
Guo et al. (2020)	✓	*1M-2R*	✓	
Jain and Hazra (2020)	✓	*N-M*	✓	
Liu et al. (2012)	✓	*1M-1R, 2M-1R,* *2M-2R*		
Raj et al. (2018)	✓	*1M-1R*		
Raj et al. (2021)	✓	*1M-1R*		
Shang et al. (2016)		*1M-1R, 2M-1R*	✓	✓
Panja and Mondal (2020)	✓			
Zhang (2002)		*1M-2R*	✓	✓
Our Paper	✓	*2M-1R*	✓	✓

Note: M: Manufacturer; R: Retailer; B: Buyer; S: Supplier; ✓: covered in the literature; ×: not covered in the literature

chain literature. We consider an affine information structure as consistent with prior literature:$E[\epsilon|x_i, x_j] = \gamma_0 + \gamma_1 x_i + \gamma_2 x_j$. Here, γ_0, γ_1 and and γ_2 are constant and, are statistically independent conditional on ϵ. To avoid negative demand intercept, we assume that b is sufficiently large to the standard deviation σ of ϵ. This information structure includes prior posterior conjugate pairs like normal-normal, β-binomial, and γ-Poisson.

The retailer has access to a demand signal x_i, which is an unbiased estimate of ϵ and is regulated by the following two assumptions: $E[\epsilon|x_i] = E[x_j|x_i] = \frac{1}{1+s}x_i$ and $E[\epsilon|x_i, x_j] = E[x_j|x_i, x_j] = \frac{1}{2+s}(x_i + x_j)$ where s is inaccuracy of demand signals which is defined as $s = \frac{E[var(x_i|\epsilon)]}{var(\epsilon)}$. It can be easily verified that $E[x_i^2] = (1+s)\sigma^2$ and $E[x_i x_j] = \sigma^2$. These assumptions are consistent with prior literature.

The manufacturer produces the green products and sells them to a retailer at a per-unit price of w. Finally, the retailers sell the green products to the consumer at a given price p. We consider that the manufacturers have constant marginal production costs and retailers have constant retailing costs. Without loss of generality, we normalize these costs to be zero. The manufacturer incurs greening costs, which is $I\theta^2$, where I represents a greening investment parameter. We assume a non-linear increasing cost function, and this is consistent with prior studies. We assume that the cost of the greening effort is independent of the sales volume because they are undertaken before sales. For instance, to produce electric vehicles, a type of green product, the manufacturers need to invest in technology and related infrastructure. These investments are independent of sales volume. Recently Volkswagen AG announced to invest 89 billion euros in EV and software development over a few years[1]. Thus, we consider only the fixed costs that a firm incurs to produce green products.

We consider a multistage game. First, the manufacturers and the retailer decide contract mechanism for information sharing. In the first stage, the retailer decides whether to share his

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[1] https://economictimes.indiatimes.com/industry/renewables/toyota-vw-are-plotting-to-beat-tesla-pour-billions-into-electric-cars/articleshow/88707947.cms

information with the manufacturer(s), and the manufacturer decides whether to acquire such information. In the second stage, retailer i observes a signal x_i and simultaneously communicates it to the manufacturers. We assume truthful communication of signals. Let Y_i be the information status of manufacturer i. $Y_i = I$ means the manufacturer i is informed (the retailer shares the information with manufacturer i), and $X_i = U$ means the manufacturer i is uninformed (the retailer does not share the information with manufacturer i). Let n be the number of informed manufacturers, where $n = 0,1,$ or 2. Based on the information status, the manufacturer decides to offer a side payment to the retailer to acquire information. In the third stage, each manufacturer determines wholesale prices w and greening levels θ based on the shared information. In the fourth stage, based on wholesale price and greening level, the retailer i determines p_i to sell the product to the final consumers. Finally, the firms realize their payoffs.

EQUILIBRIUM ANALYSIS

The expected profit function of the retailer and manufacturer are, respectively, given by:

$$\begin{aligned} E[\Pi_R|w,x] &= \textstyle\sum_{i=1}^{2}(p_i - w_i)[b + \alpha\theta_i + E[\epsilon|x_i] - p_i + \lambda p_i] \\ E[\Pi_{M_i}^{I}|x] &= w_i E[q_i(w_i,w_j)|x] - I\theta_i^2 \quad \text{if manufacturer } i \text{ is uninformed} \\ E[\Pi_{M_i}^{U}] &= w_i E[q_i(w_i,w_j)] - I\theta_i^2 \quad \text{if manufacturer } i \text{ is informed.} \end{aligned}$$

We solve for the equilibrium values using the backward induction approach. The manufacturers act as Stackelberg leaders. All the derivations are presented in the Appendix. The equilibrium wholesale prices, and greening levels of the manufacturers and the retail prices are given in the following proposition.

Proposition 1: The unique equilibrium wholesale prices, greening levels and retail prices for the number of informed manufacturers n are given by

$$w_i^* = \begin{cases} \bar{w} + \beta_w(n)x & \text{if } n = 0, \text{or } 2 \\ \bar{w} + \beta_w^{Y_i}(1)x & \text{if } n = 1 \end{cases} \qquad \theta_i^* = \begin{cases} \bar{\theta} + \beta_\theta(n)x & \text{if } n = 0, \text{or } 2 \\ \bar{\theta} + \beta_\theta^{Y_i}(1)x & \text{if } n = 1 \end{cases}$$

$$p_i^* = \begin{cases} \bar{p} + \beta_p(n)x & \text{if } n = 0, \text{or } 2 \\ \bar{p} + \beta_p^{Y_i}(1)x & \text{if } n = 1 \end{cases}$$

where $\bar{w} = \frac{4Ib}{4I(2-\lambda)-\alpha^2}$, $\bar{\theta} = \frac{\alpha b}{4I(2-\lambda)-\alpha^2}$, $\bar{p} = \frac{2Ib(3-2\lambda)}{\delta(1-\lambda)}$, and

$$\begin{aligned} \beta_w(0) &= \beta_w^U(1) = 0, & \beta_\theta(0) &= \beta_\theta^U(1) = 0, \\ \beta_w^I(1) &= \frac{4I}{(8I-\alpha^2)(1+s)}, & \beta_\theta^I(1) &= \frac{\alpha}{(8I-\alpha^2)(1+s)} \\ \beta_w(2) &= \frac{4I}{(4I(2-\lambda)-\alpha^2)(1+s)}, & \beta_\theta(2) &= \frac{\alpha}{(4I(2-\lambda)-\alpha^2)(1+s)} \end{aligned}$$

$$\begin{aligned} \beta_p(0) &= \beta_p^U(1) = \frac{1}{2(1-\lambda)(1+s)}, \quad \beta_p^I(1) &&= \frac{4I(1+\lambda)(3-\lambda)+\alpha^2(1-\lambda)}{2(1-\lambda^2)(8I-\alpha^2)(1+s)} \\ \beta_p(2) & &&= \frac{4I(3-2\lambda)+\alpha^2}{2(1-\lambda)(4I(2-\lambda)-\alpha^2)(1+s)} \end{aligned}$$

Proposition 1 indicates that in the equilibrium, the retailer adjusts its retail price and the informed manufacturer adjusts its wholesale price and greening levels according to demand signal x as per linear strategy. It can also be observed that the decision of an uninformed manufacturer is independent of the demand signal x. This is because the informed manufacturer and retailer leverage demand information and adjust their decision as per the demand signal. We can also observe that w_i^*, p_i^*, and θ_i^* become higher when the signal accuracy increases (i.e. s decreases) and consumer sensitivity towards greening increases.

We can see that $\beta_w(2) > \beta_w(1)^I$ and $\beta_\theta(2) > \beta_\theta^I(1)$, it implies that the equilibrium wholesale prices and greening levels are highest if both the manufacturers are informed, smallest if none of them are informed, and take intermediate values when one manufacturer is informed. A larger x indicates more optimistic demand; thus, it induces the retailer to order a large quantity from the manufacturers. In response to a large order, manufacturers incur a higher greening cost. To recover the extra greening costs, the manufacturer charges a higher wholesale price when the retailer shares the demand information with the manufacturers. However, the wholesale prices are distorted when the retailer shares the demand information with only one manufacturer. This is due to the signaling effect. It emerges because the uninformed manufacturer infers the demand information from the wholesale price charged by the informed manufacturer.

When $\lambda = 0$ (means that both the product are independent), $\beta_w(2) = \beta_w(1)^I$, the informed manufacturer charges the same wholesale price irrespective of the rival manufacturer's information status. When only one manufacturer is informed, $\beta_w^I(1)$ is independent of λ. This is because only the constant part of the informed manufacturer's wholesale price is affected. When both are informed, $\beta_w(2)$ is positively associated with the competition intensity. We further observe that the equilibrium greening levels are increasing with competition intensity. This indicates that price competition is one of the antecedents to increasing the greening levels of the products.

We calculate the ex-ante expected profits of the manufacturers and the retailer by taking the expectation with respect to the demand signal x before the demand signal is observed. Let $\pi_M(n)$ for $n = 0$ or 2, and $\pi_M^{Y_i}(n)$ for $n = 1$. Retailer's ex-ante profit is given by $\pi_R(n)$:

Proposition 2: The equilibrium ex-ante profits of the manufacturer and the retailer for the number of informed manufacturers n are given by

$$\begin{array}{llll}
\Pi_M^*(0) & = \Pi_M^{*U}(1) = \bar{\pi}_M & \Pi_R^*(0) & = \bar{\pi}_R \\
\Pi_M^{*I}(1) & = \bar{\pi}_M + \dfrac{I}{(8I-\alpha^2)(1+s)}\sigma^2 & \Pi_R^*(1) & = \bar{\pi}_R - \dfrac{(2I(1-\lambda^2)-\alpha^2)(6I(1-\lambda^2)+\alpha^2\lambda^2)}{(1-\lambda^2)^2(8I-\alpha^2)^2(1+s)}\sigma^2 \\
\Pi_M^{*I}(2) & = \bar{\pi}_M + \dfrac{I(8I-\alpha^2)}{\Delta^2(1+s)}\sigma^2 & \Pi_R^*(2) & = \bar{\pi}_R - \dfrac{4I(3-\lambda)(2I(1-\lambda)-\alpha^2)}{\Delta^2(1-\lambda)(1+s)}\sigma^2
\end{array}$$

where $\Delta = 4I(2-\lambda) - \alpha^2$, $\bar{\pi}_M = \frac{Ib^2(8I-\alpha^2)}{\Delta^2}$ and $\bar{\pi}_R = \frac{8(Ib)^2}{\Delta^2} + \frac{1}{2(1-\lambda)(1+s)}\sigma^2$.

Proposition 2 highlights the equilibrium profits of the manufacturers and the retailer, and they are increasing with α and decreasing with I. The equilibrium profit of the manufacturer (retailer) is decreasing (increasing) with the inaccuracy of demand signal s. When $s = 0$, the ex-ante profits of the manufacturers are the highest because they leverage complete information to make better decisions under demand uncertainty. We can also observe that manufacturers are better off while the retailer is worse off with information sharing. The ranking of their profits is given in the following proposition.

Proposition 3: The rankings of the manufacturers' and retailer's ex-ante profits under different information sharing cases are as follows: (a) $\Pi_M^*(2) > \Pi_M^{*I}(1) > \Pi_M^*(0)$, and (b) $\Pi_R^*(0) > \Pi_R^*(1) > \Pi_R^*(2)$ if $I > \frac{\alpha^2\lambda(2-\lambda)}{8(1+\lambda)^2(1-\lambda)(3-\lambda)}$.

Proposition 3 highlights that manufacturers would like to acquire more information from the retailer. Therefore, information sharing benefits the manufacturers but hurts the retailer and the uninformed rival manufacturer. The greening investment is costly as $I > \frac{\alpha^2\lambda(2-\lambda)}{8(1+\lambda)^2(1-\lambda)(3-\lambda)}$. Therefore, the informed manufacturer adjusts w_i upward with demand signal x and this leads to (a) higher double marginalization (b) reduces the order uncertainty q_i, and (c) increases the order uncertainty of q_j. Thus, (a) and (b) benefit the manufacturer i, and (a) hurts the retailer. Part (c) hurts the manufacturer j if she is uninformed. Otherwise, it could adjust w_j in response to demand signal to hedge against demand uncertainty to increase its profit. We also observe manufacturers' and retailers' information sharing depends on competition intensity. It suggests that more intense competition between the manufacturers induces the retailer to share information with more manufacturers. More intense competition reduces the double marginalization problem and makes information sharing more valuable.

ANALYSIS OF GREENING LEVEL

The equilibrium greening levels in partial and full information sharing are denoted by $\theta(1)$ and $\theta(2)$, respectively. The equilibrium greening level is higher in full than partial information sharing cases because $\beta_\theta(2) > \beta_\theta(1)$ for any λ, α and s. This is because $\beta_\theta(1)$ does not depend on competition parameter λ, but $\beta_\theta(2)$ depends on λ. This implies that when the retailer shares the demand information with both the manufacturers, competition induces them to differentiate their products from their rivals with more greening efforts. By doing so, they expect to attract more green consumers. However, as the signal inaccuracy increases, the equilibrium greening levels in the full information sharing case converge to those in the partial information sharing case. This is because the information is no longer an effective tool for differentiation. This is shown in Figure 1.

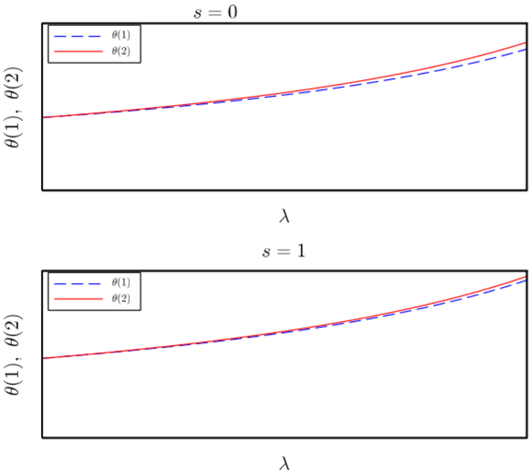

Figure 1. Equilibrium Greening Levels in Full and Partial Information Sharing

We also make the following observations regarding equilibrium greening levels in case of partial and full-information cases:

1. The equilibrium greening level increases with the consumers' preference for green products in the partial as well as full information sharing cases, i.e., $\frac{\partial\theta(i)}{\partial\alpha} > 0$ for $i = 1,2$.
2. The equilibrium greening level increases with the competition in the partial as well as full information sharing cases, i.e., $\frac{\partial\theta(i)}{\partial\lambda} > 0$ for $i = 1,2$.
3. The equilibrium greening level decreases with the retailer's signal inaccuracy in partial as well as full information sharing cases, i.e., $\frac{\partial\theta(i)}{\partial s} < 0$ for $i = 1,2$.

INCENTIVE FOR INFORMATION SHARING

For the manufacturers, acquiring demand information from the retailer is always better. For the retailer, sharing the demand information with any manufacturers is not beneficial. Thus, it is interesting to analyze a suitable mechanism that can drive both manufacturer and retailer to share the demand information. We design information-sharing contracts between the manufacturers and the retailer, which is mutually rewarding. In the case of an information-sharing agreement, the retailer simultaneously demands a side payment T from each manufacturer. Then, each manufacturer decides whether to accept the offer.

Let T be the payment demanded by the retailer. There are two strategies $Y_i = I$ and $Y_i = U$ for the manufacturer. When she agrees to pay the retailer for the demand information, the manufacturer is informed and $X_i = I$. When she does not agree to pay the retailers for the demand information, the manufacturer is uninformed and $X_i = U$. The retailer approaches both the manufacturers simultaneously, demanding a payment of T for sharing his demand information. Then the manufacturing decides to accept the offers. Using backward induction, we solve the problem by solving the manufacturer game for given payment T. As per ex-ante profits and payment T, we find the payoffs of the manufacturers, which are shown in Table 2.

Table 2. Payoff Matrix of the Manufacturers under Simultaneous Information Contracting

		Manufacturer 2	
		I	**U**
Manufacturer 1	I	$\Pi_M^*(2) - T,\ \Pi_M^*(2) - T$	$\Pi_M^{*I}(1) - T,\ \Pi_M^{*U}(1) - T$
	U	$\Pi_M^{*U}(1) - T,\ \Pi_M^{*I}(1) - T$	$\Pi_M^*(0) - T,\ \Pi_M^*(0) - T$

We get a cut-off strategy for the retailer to share the information. It is given in the following Proposition 4.

***Proposition 4**: The retailer will share the information with both the manufacturers if $0 < I < \bar{I}$ and will share the information with no one if $I \geq \bar{I}$, where $\bar{I} = \frac{\alpha^2(5-\lambda)}{4(1-\lambda)^2}$.*

Proposition 4 implies that if the greening investment is lower than a threshold level $\bar{I}$, then the retailer shares the information with both manufacturers with payment T. If the manufacturer is efficient in greening, the retailer would like to share the information. This is because, in the case of information sharing, the manufacturer increases the wholesale price in response to the demand signal, which inflates double marginalization problem. However, if the manufacturer is efficient in greening, it produces the same amount of green products with less investment. Therefore, it offset the double marginalization effect. Thus, if the manufacturer is efficient in greening, it leads to information sharing between the manufacturers and the retailer. We can also observe that $\bar{I}$ is increasing with α and λ. If

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consumers' sensitivity increases, it compels the manufacturers to invest in greening and prefer to buy information from the retailers. Further, in case of intense competition, the manufacturer would like to purchase demand information from the retailer for better decisions.

CONCLUSION

In this study, we analyze the problem of promoting information sharing and optimizing the products' greening level in a supply chain when the retailer holds the demand information privately. We also examine the issue of information sharing when two competing manufacturers sell their green products in markets through a common retailer. Our result suggests that there exists a unique equilibrium of information sharing. We demonstrate conditions under which information sharing benefits the player in the supply chain. We find a payment that the manufacturer could use to induce the retailer to share his demand information, if the retailer conveys his information truthfully.

However, it might be possible that the retailer would not tell the truth about his demand information. In this case, it requires some mechanisms to enforce truthful communication, and we leave this for future research. This study also assumes that the retailer shares the information simultaneously and lets the manufacturers reach a Nash equilibrium. It is important to analyze whether the retailer could be better off communicating with two manufacturers sequentially or simultaneously in future studies.

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APPENDIX

In this section we consider two competing manufacturers and one common retailer. The manufacturers first decide their wholesale prices and greening levels, then the retailer decides the optimal retailer price given her signal and wholesale prices and greening levels. The demand for product *i* is

$$q_i = b + \alpha\theta_i + \epsilon - p_i + \lambda p_j. \tag{1}$$

where p_i is the price of product *i* and p_j is the price of product *j*. Note that here prices p_i and p_j are not the prices of two different retailers. They are the prices of two different products produced by two different manufacturers.

The retailer maximizes his conditional expected profit at the last stage:

$$E[\Pi_R|w,x] = \max_{p_1,p_2}(p_1 - w_1)[b + \alpha\theta_1 + E[\epsilon|x] - p_1 + \lambda p_2] + (p_2 - w_2)[b + \alpha\theta_2 + E[\epsilon|x] - p_2 + \lambda p_1]$$

Taking first order conditions and solving for p_i in terms of w_i and w_j, we get the following reaction function of the retailer

$$p_i = \frac{b+E[\epsilon|x]+(1-\lambda)w_i}{2(1-\lambda)} + \frac{\alpha(\lambda\theta_j+\theta_i)}{2(1-\lambda)(1+\lambda)} \quad \text{for } i,j = 1,2 \text{ and } i \neq j \tag{2}$$

The demand function after substituting the prices p_i and p_j in Equation (1) is equal to

$$q_i(w_i,w_j) = \frac{1}{2}(b + \alpha\theta_i + E[\epsilon|x] - w_i + \lambda w_j) + \epsilon - E[\epsilon|x] \tag{3}$$

We consider two cases when a particular manufacturer is *informed (I)* or *uninformed (U)*. When a manufacturer is informed or uninformed, her conditional expected demand is $E[q_i(w_i,w_j)|x]$ or $E[q_i(w_i,w_j)]$, respectively. Therefore, the conditional expected profit function of informed manufacturer is

$$\begin{aligned} E[\Pi_{M_i}^I|x] &= w_i E[q_i(w_i,w_j)|x] - I\theta_i^2 \\ &= \frac{w_i}{2}(b + \alpha\theta_i - w_i + \lambda E[w_j] + E[\epsilon|x]) - I\theta_i^2 \end{aligned}$$

Since the manufacturer is informed, $E[w_j] = w_j$ for calculating the Bayesian Nash equilibrium. The final expression for conditional expected profit of an informed manufacturer reduces to

$$E[\Pi_{M_i}^I|x] = \frac{w_i}{2}(b + \alpha\theta_i - w_i + \lambda w_j + E[\epsilon|x]) - I\theta_i^2 \tag{4}$$

Similarly, the expected profit of uninformed manufacturer is

$$E[\Pi_{M_i}^U] = w_i E[q_i(w_i,w_j)] - I\theta_i^2 = \frac{w_i}{2}(b + \alpha\theta_i - w_i) + \lambda E[w_j]) - I\theta_i^2$$

where $E[\epsilon] = 0$ and $E[E[\epsilon|x]] = 0$.

Taking the first order conditions of 4 with respect to w_i and ϑ_i, we obtain

$$\frac{\partial E\left[\Pi^I_{M_i}|x\right]}{\partial w_i} = \frac{1}{2}\left(b + \alpha\theta_i - 2w_i + \lambda w_j + E[\epsilon|x]\right) = 0 \tag{5}$$

$$\frac{\partial E\left[\Pi^I_{M_i}|x\right]}{\partial \theta_i} = \frac{\alpha w_i}{2} - 2I\theta_i = 0 \tag{6}$$

Solving Equations 5 and 6 simultaneously, we obtain the best response functions of informed manufacturer M_i as a function of w_j

$$w_i(w_j) = \frac{4I\left(b+E[\epsilon|x]+\lambda w_j\right)}{8I-\alpha^2}, \quad \theta_i(w_j) = \frac{\alpha\left(b+E[\epsilon|x]+\lambda w_j\right)}{8I-\alpha^2}$$

Similarly, we obtain the best response function of the uninformed manufacturer as a function of w_j

$$w_i(w_j) = \frac{4I\left(b+\lambda E[w_j]\right)}{8I-\alpha^2}, \quad \theta_i(w_j) = \frac{\alpha\left(b+\lambda E[w_j]\right)}{8I-\alpha^2}$$

The wholesale prices and greening levels in equilibrium are given in Proposition 1.

UNINFORMED CASE

When both the manufacturers are uninformed, their reaction functions are given by

$$w_1 = \frac{4I(b+\lambda w_2)}{8I-\alpha^2}, \qquad w_2 = \frac{4I(b+\lambda w_1)}{8I-\alpha^2}$$

Solving them simultaneously, we get

$$w_1^* = w_2^* = \frac{4Ib}{4I(2-\lambda)-\alpha^2}$$

Putting the value of w_i* in ϑ_i, we get

$$\theta_i^* = \frac{\alpha b}{4I(2-\lambda)-\alpha^2} \qquad \text{for } i = 1,2.$$

INFORMED CASE

When both the manufacturers are informed, their reaction functions are given by

$$w_1 = \frac{4I(b+\lambda w_2+2E[\epsilon|x])}{8I-\alpha^2} \qquad w_2 = \frac{4I(b+\lambda w_1+2E[\epsilon|x])}{8I-\alpha^2}$$

Solving them simultaneously, we get

$$\begin{aligned} w_1^* = w_2^* &= \frac{4Ib+8IE[\epsilon|x]}{4I(2-\lambda)-\alpha^2} \\ &= \frac{4Ib}{4I(2-\lambda)-\alpha^2} + \frac{8I}{(4I(2-\lambda)-\alpha^2)(1+s)}x \end{aligned}$$

Putting the value of w_i^* in the equation for ϑ_i, we get

$$\theta_i^* = \frac{\alpha b}{4I(2-\lambda)-\alpha^2} + \frac{2\alpha}{(4I(2-\lambda)-\alpha^2)(1+s)} x$$

PARTIALLY INFORMED CASE

Manufacturer 1 is informed and manufacturer 2 is not informed.
Their reaction functions are given by

$$w_1 = \frac{4I(b+\lambda w_2+2E[\epsilon|x])}{8I-\alpha^2} \qquad w_2 = \frac{4I\big(b+\lambda E(w_1)\big)}{8I-\alpha^2}$$

Taking the expectation of w_1, we get

$$E(w_1) = \frac{4I(b+\lambda w_2)}{8I-\alpha^2} \quad \because E\big[E[\epsilon|x]\big] = 0 \text{ and } E(w_2) = w_2$$

Substituting this value into w_2, we get w_2^*, which is given by

$$w_2^* = \frac{4Ib}{4I(2-\lambda)-\alpha^2}$$

Substituting this, we get the expression for w_1^*.

Putting the equilibrium values of w_i^* and θ_i^* for $i = 1,2$ of their respective cases in the following equation

$$p_i = \frac{b+E[\epsilon|x]+(1-\lambda)w_i^*}{2(1-\lambda)} + \frac{\alpha\big(\lambda\theta_j^*+\theta_i^*\big)}{2(1-\lambda)(1+\lambda)} \quad \text{for } i,j = 1,2 \text{ and } i \neq j$$

we get the expression for p^* in each case. Taking the expectation of

$$q_i(w_i, w_j) = \frac{1}{2}\big(b + \alpha\theta_i + E[\epsilon|x] - w_i + \lambda w_j\big) + \epsilon - E[\epsilon|x]$$

when the manufacturer is uniformed or informed, we obtain

$$E\big[q_i(w_i, w_j)\big] = \frac{1}{2}\big(b + \alpha\theta_i - w_i + \lambda w_j\big) \quad \text{uninformed manufacturer} \qquad (7)$$

$$E\big[q_i(w_i, w_j)|x\big] = \frac{1}{2}(b + \alpha\theta_i - w_i + \lambda w_j + E[\epsilon|x]) \quad \text{informed manufacturer} \qquad (8)$$

From the first order condition of uninformed and informed manufacturer, we get

$$E\big[q_i(w_i, w_j)\big] = \frac{1}{2} w_i \qquad (9)$$

$$E\big[q_i(w_i, w_j)|x\big] = \frac{1}{2} w_i \qquad (10)$$

Thus, the expected profit function for uninformed, only one informed or both informed are

$$E[\Pi_M^*(0)] = \frac{1}{2} w_i^{*2}(0) - I\theta_i^{*2} \tag{11}$$

$$E[\Pi_M^{*I}(1)] = \frac{1}{2} w_i^{*I2}(1) - I\theta_i^{*I2} \tag{12}$$

$$E[\Pi_M^*(2)] = \frac{1}{2} w_i^{*2}(2) - I\theta_i^{*2} \tag{13}$$

Substituting the optimal values of w_i^* and ϑ_i^*, we get

$$\begin{aligned} E\left[\Pi_{M_i}^{*U}(0)\right] &= E\left[\Pi_{M_i}^{*U}(1)\right] = \frac{I(8I-\alpha^2)b^2}{\delta^2} \\ E\left[\Pi_{M_i}^{*I}(1)\right] &= I(8I - \alpha^2)[\frac{b}{\delta} + \frac{1}{(8I-\alpha^2)(1+s)} x]^2 \\ E\left[\Pi_{M_i}^{*I}(2)\right] &= \frac{I(8I-\alpha^2)}{\delta^2} [b + \frac{1}{(1+s)} x]^2 \end{aligned}$$

Taking the expectation with respect to x, we get the required result.

RETAILER'S EX ANTE EQUILIBRIUM PROFIT

From the first order condition of the retailer's maximization problem, we can obtain

$$b + \alpha\vartheta_i + E[\epsilon|x] - p_i + \lambda p_j = (p_i - w_i) - \lambda(p_j - w_j)$$

This is just the expected demand of the retailer for product *i*

$$E(q_i|x) = (p_i - w_i) - \lambda(p_j - w_j)$$

Now we can write the optimal profit function of the retailer as

$$E[\Pi_R^*|x] = (p_i^* - w_i^*)E(q_i^*|x) + (p_j^* - w_j^*)E\left[q_j^*|x\right] \tag{14}$$

$$= (p_i^* - w_i^*)^2 - 2\lambda(p_i^* - w_i^*)(p_j^* - w_j^*) + (p_j^* - w_j^*)^2 \tag{15}$$

CASE I

The retailer does not share her information with any manufacturer. Since p^*_i and w_i^* are symmetric for this case, we can simply write the optimal expected profit as

$$\begin{aligned} E[\Pi_R^*(0)] &= [p_i^*(0) - w_i^*(0)]^2 - 2\lambda[p_i^*(0) - w_i(0)^*]^2 + [p_i^*(0) - w_i^*(0)]^2 \\ &= 2(1-\lambda)[p_i^*(0) - w_i^*(0)]^2 \end{aligned} \tag{16}$$

Calculating the value of $(p_i^*(0) - w_i^*(0))$, we obtain

$$\begin{aligned}\left(p_i^*(0)-w_i^*(0)\right) &= \frac{2Ib(3-2\lambda)}{\delta(1-\lambda)}+\frac{1}{2(1-\lambda)(1+s)}x-\frac{4Ib}{\delta} \\ &= \frac{2Ib}{\delta(1-\delta)}+\frac{1}{2(1-\lambda)(1+s)}x\end{aligned} \tag{17}$$

Substituting Equation 17 into Equation 16, we get

$$E[\Pi_R^*(0)] \quad = \frac{2}{(1-\lambda)}(\frac{2Ib}{\delta}+\frac{1}{2(1+s)}x)^2$$

Taking the expectation with respect to *x*, we get the result.

CASE II

The retailer shares her information with only manufacturer *i* and does not share it with manufacturer *j*. The expected profit for this case can be written as

$$E[\Pi_R^*(1)] = \left[p_i^{*I}(1)-w_i^{*I}(1)\right]^2-2\lambda\left[p_i^{*I}(1)-w_i(1)^{*I}\right]\left[p_j^{*U}(1)-w_j^{*U}(1)\right]+\left[p_j^{*U}(1)-\right.$$
$$\left.w_j^{*U}(1)\right]^2$$

We can rewrite this as

$$E[\Pi_R^*(1)] = [p_i^{*I}(1)-w_i^{*I}(1)][(p_i^{*I}(1)-w_i^{*I}(1)-\lambda(p_j^{*U}(1)-w_j^{*U}(1)))]+[p_j^{*U}(1)-w_j^{*U}(1)]$$
$$[(p_j^{*U}(1)-w_j^{*U}(1)-\lambda(p_1^{*I}(1)-w_i^{*I}(1)))] \tag{18}$$

Calculating the value of $\left(p_i^{*I}(1)-w_i^{*I}(1)\right)$ and $p_j^{*U}(1)-w_j^{*U}(1)$, we obtain

$$\left(p_i^{*I}(1)-w_i^{*I}(1)\right)=\frac{2Ib}{\delta(1-\lambda)}+\frac{\alpha^2-2I(1-\lambda^2)}{(1-\lambda^2)(8I-\alpha^2)(1+s)}x+\frac{1}{2(1-\lambda)(1+s)}x \tag{19}$$

$$p_j^{*U}(1)-w_j^{*U}(1)=\frac{2Ib}{\delta(1-\lambda)}+\frac{1}{2(1-\lambda)(1+s)}x \tag{20}$$

Therefore, we can calculate

$$[p_i^{*I}(1)-w_i^{*I}(1))-\lambda(p_j^{*U}(1)-w_j^{*U}(1)]=\frac{2Ib}{\delta}+\frac{\left(\alpha^2-2I(1-\lambda^2)\right)}{(1-\lambda^2)(8I-\alpha^2)(1+s)}x+\frac{1}{2(1+s)}x \tag{21}$$

$$[p_j^{*U}(1)-w_j^{*U}(1))-\lambda(p_i^{*I}(1)-w_i^{*I}(1)]=\frac{2Ib}{\delta}-\frac{\lambda\left(\alpha^2-2I(1-\lambda^2)\right)}{(1-\lambda^2)(8I-\alpha^2)(1+s)}x+\frac{1}{2(1+s)}x \tag{22}$$

Substituting Equations 19, 20, 21 and 22 into Equation 18 and rearranging, we get

$$\begin{aligned}E[\Pi_R^*(1)] \quad &= \frac{2}{(1-\lambda)}(\frac{2Ib}{\delta}+\frac{1}{2(1+s)}x)^2+\frac{\alpha^2-2I(1-\lambda^2)}{(1-\lambda^2)(8I-\alpha^2)(1+s)}x \\ &\quad [\frac{4Ib}{\delta}+\frac{\left(\alpha^2-2I(1-\lambda^2)\right)}{(1-\lambda^2)(8I-\alpha^2)(1+s)}x+\frac{1}{(1+s)}x]\end{aligned}$$

Taking the expectation with respect to *x*, we get the result.

CASE III

The retailer shares her information with both the manufacturers. Since p^*_i and w_i^* are symmetric for this case also, we can simply write the optimal expected profit as

$$E[\Pi_R^*(2)] \quad = 2(1-\lambda)[p_i^*(2) - w_i^*(2)]^2 \tag{23}$$

Calculating the value of $\left(p_i^*(2) - w_i^*(2)\right)^2$, we obtain

$$\left(p_i^*(2) - w_i^*(2)\right) \quad = \frac{2Ib(3-2\lambda)}{\delta(1-\lambda)} + \frac{\left(\alpha^2+2I(1-\lambda)\right)}{\delta(1-\lambda)(1+s)}x + \frac{1}{2(1-\lambda)(1+s)}x - \frac{4Ib}{\delta} - \frac{4I}{\delta(1+s)}x$$

Simplifying, we get

$$p_i^*(2) - w_i^*(2) \quad = \frac{2Ib}{\delta(1-\lambda)} + \frac{\left(\alpha^2-2I(1-\lambda)\right)}{\delta(1-\lambda)(1+s)}x + \frac{1}{2(1-\lambda)(1+s)} \tag{24}$$

Substituting Equation 24 into Equation 23, we get

$$E[\Pi_R^*(2)] \quad = \frac{2}{(1-\lambda)}[\frac{2Ib}{\delta} + \frac{\alpha^2-2I(1-\lambda)}{\delta(1+s)}x + \frac{1}{2(1+s)}x]^2$$

Taking the expectation with respect to *x*, we get the result.

PROOF OF PROPOSITION 3

It is obvious that $\pi_R^*(0) > \Pi^*(1)$. To show that $\pi^*(1) > \Pi^*(2)$, we have to argue that

$$\frac{(2I(1-\lambda^2)-\alpha^2)(6I(1-\lambda^2)+\alpha^2\lambda^2)}{(1-\lambda)^2(8I-\alpha^2)^2} - \frac{4I(3-\lambda)(2I(1-\lambda)-\alpha^2)}{\delta^2(1-\lambda)} < 0$$

This is going to be true when

$$I > \frac{\alpha^2\lambda(2-\lambda)}{8(1+\lambda)^2(1-\lambda)(3-\lambda)}$$

PROOF OF PROPOSITION 4

If $T \leq \Pi_M^*(1) - \Pi_M^*(0)$, then I is the dominant strategy for both the manufacturers. Thus, the dominants strategy equilibrium is (I, I). If $T \geq \Pi_M^*(2) - \Pi_M^*(0)$, then (U, U) is the dominant strategy equilibrium. If $\Pi_M^*(2) - \Pi_M^*(0) \leq T \leq \Pi_M^*(1) - \Pi_M^*(0)$, then (I, I) and (U, U) are two equilibria. We choose the Pareto optimal equilibrium, that is (I, I).

Take $T = \Pi_M^*(2) - \Pi_M^*(0)$, Then the retailer will share the information with both the manufacturer if and if $2[\Pi_M^*(2) - \Pi_M^*(0)] > \Pi_R^*(0) - \Pi_R^*(2)$. We can rewrite the inequality as $\Pi_R^*(2) + 2\Pi_M^*(2) - [\Pi_R^*(0) + 2\Pi_M^*(0)] > 0$. This inequality will hold only if

$$I > \frac{\alpha^2(5-\lambda)}{4(1-\lambda)^2}.$$