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Channel Coordination in a Green Supply Chain in the presence of Demand Expansion Effects

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Channel Coordination in a Green Supply Chain in the Presence of Demand Expansion Effects

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Abstract

We consider the problem of a single manufacturer who sells its products to a single retailer. The manufacturer puts in some effort for greening its operations, and the retailer also puts in a corresponding greening effort in retailing the product. Their respective greening efforts are considered to have "expansion" effects on the retail demand. The manufacturer makes decisions on the wholesale prices and its greening efforts, while the retailer makes decisions on the retail price and its corresponding greening efforts.

Our results show that: (i) The ratio of the optimal greening efforts put in by the manufacturer and retailer is equal to the ratio of their green sensitivity ratios and greening cost ratios. This result holds irrespective of whether it is an integrated or a decentralized channel, (ii) Profits are higher and efforts are higher in the integrated channel as compared to the case of the decentralized channel. This is consistent with the earlier research in the channels literature, (iii) Interestingly, however, we find that, under certain conditions, optimal prices are higher in the integrated channel as compared to the case of the decentralized channel. This is not consistent with the usual 'double marginalization' explanation given in the channels literature, (iv) By and large, the above results replicate themselves in the cases in which only one of the two channel members (i.e., either manufacturer or retailer) puts in the greening effort, (v) A two-part tariff contract from the manufacturer to the retailer, which takes into account the relevant parameters of prices and greening efforts, can produce the desired effect of channel coordination in this problem. A numerical example illustrates some of these results.

[Key words: Green supply chain management, Supply chain coordination, Distribution channels]

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1 Introduction

The World Summit on Sustainable Development (2002) in Johannesburg proposed a triplet term *people* - *planet* - *prosperity* to reflect the fact that sustainable development required balancing of social, economic and environmental issues (White and Lee 2007). Indeed, in the recent past, the concept of environmental consciousness has become intimately intertwined with both everyday life and sound business practices (Intergovernmental Panel on Climate Change 2007).

Traditionally, from the business perspective, the issue of environmental consciousness, or “green management”, had raised a conundrum in which economic concerns were perceived at odds with the ecological concerns. Lately, however, the literature has begun to recognize the needlessness of this “stalemate” between being green and competitive (Porter and van der Linde 1995; Rao and Holt 2005). Examples have begun to emerge from practice regarding the economic benefits of the adoption of the green practices. For example, Commonwealth Edison reported financial benefits of $50 million annually from managing material and equipment with a life-cycle management approach. Pepsi-Cola saved $44 million by switching from corrugated to reusable plastic shipping containers for one liter and 20-ounce bottles. Similar savings have been reported by Texas Instruments and Dow Corning (Wilkerson 2005).

From a distribution (a marketing view) or a supply chain (an operations view) perspective, the phenomenon of green management has opened up several interesting and challenging problems for both the practitioners and researchers. In response to these challenges, a relatively new stream of research has emerged, which is labeled as green supply chain management (referred as GrSCM hereafter, Srivastava 2007). A number of research issues have been addressed in this area ranging from green design (Zhang et al. 1997), reverse logistics (Flieschmann et al. 1997), product recovery (Gungor and Gupta 1999), logistics design (Jayaraman et al. 2003), and so on.

One of the important research areas in supply chain management is related to the conflict and coordination issues that can arise between various players in the chain. These issues or conflicts can be both horizontal and vertical in nature. The horizontal conflicts are between the players at the same level of the supply chain, while the vertical conflicts are between the players at the upstream (say, a manufacturer) and downstream (say, a retailer) levels of the chain.

In the current research, we focus on the vertical conflicts in a green supply chain. Any major greening project would require efforts on the part of both retailer and supplier. As Wal-Mart discovered while launching green supply chain management initiatives that, focusing on its internal operations alone, it would be limiting itself to only 10% of potential greening opportunities (Plambeck 2007). Thus, Wal-Mart decided to focus on entire value chain and not just within Wal-Mart boundary. However, a pertinent question arises in more general situations across the supply chain: Who should be investing in the greening effort? Should it be retailer or manufacture or both? Should they work on greening initiative independently or should entities in chain coordinate their greening effort? We aim to address some of these concerns in the current paper.

Starting from the seminal papers on channel coordination in marketing literature (McGuire and Staelin 1983; Jeuland and Shugan 1983), considerable research has been done in the area of channel conflicts on the issues ranging from strategic decentralization (Moorthy 1988), manufacturers' competition (Choi 1991), quantity discounts and two-part tariffs (Ingene and Parry 1995); vertical strategic interaction (Lee and Staelin 1997), benefits of channel discord (Arya and Mittendorf 2006), demand perishability (Raut et al. 2007), and so on. With the general assumption of a deterministic demand function, the above stream of research has been able to focus on a variety of issues as listed above.

Another stream of research in the supply chain coordination has taken the route of modeling the role of stochastic demand in supply chain coordination. This stream of research is grounded in the classical newsvendor problem. Various models have extended the newsvendor model by allowing the retailer to choose his retail price in addition to his stocking quantity, retailer to exert costly effort to increase demand, tempering of downstream competition, stochastic demand with multiple replenishment opportunities, infinite horizon model, making the supplier hold inventory, transfer prices, information asymmetry, and so on. An excellent review of this stream of research appears in Cachon (2003).

As evident from the discussion above, although considerable amount of research has been done in the above areas, very few studies have addressed the issue of coordinating the green supply chain. Yet, a characteristically different set of conflicts between channel partners, and the requirement for coordination thereof, may arise in situations involving green supply chains. Some examples of such conflicts include different incentives for the channel partners to invest in green practices, the effect of investments in greening efforts on price determination, competition among green suppliers, competition among green retailers, reverse channel design, and so on. Lately, some research has begun to emerge in the research area of the coordination of green supply chain (Goldbach, Seuring and Back 2003; Vachon and Klassen 2006; Savaskan and van Wassenhove 2006; Mitra and Webster 2008).

While we elaborate on the above studies in the next section on the background literature; from the modeling standpoint, the study that comes closest to our approach in this paper is Savaskan and Van Wassenhove's (2006) (referred as SVW (2006) hereafter) on reverse channel design. In their paper, SVW (2006) discuss the major problem of the interaction between a manufacturer's reverse channel choice to collect postconsumer goods and the strategic product pricing decisions in the forward channel. They provide a comparison between both direct (i.e. manufacturer collects used products) and indirect (retailer collects) product collection systems. This comparison is done for both centralized and decentralized systems.

The main focus of SVW (2006) is on the reverse channel design. However, as per the taxonomy provided by Srivastava (2007), there are other factors that also influence the broad area of GrSCM, such as, green design, green manufacturing and remanufacturing, importance or image related advantages, etc. In particular, from a modeling perspective, the major motivation of including reverse channel decisions in the strategic framework of SVW (2006) comes in the form of a cost-reduction provided by the use of recycled material in the reverse channel. In this paper, we argue that there may also be other influences on the profit equation. Specifically, we focus on the demand expansion effects of greening efforts.[1] The *demand expansion* effect represents a situation

[1] Another effect, the *price premium* effect, is representative of the behavior of a consumer who is willing to pay extra for a green product. However, we do not include this aspect in the current paper.

in which, given two otherwise equivalent products, the market prefers a green product over the non-green products**.**

There are some points worth mentioning about the demand expansion effects of greening. First, a natural question arises: are consumers even bothered about green issues? Recently, Bonini and Oppenheim (2008) reported that "…according to a 2007 McKinsey survey of 7,751 people in Brazil, Canada, China, France, Germany, India, the United Kingdom, and the United States…87 percent of consumers worry about the environmental and social impact of the products they buy." (p. 1). Thus, there is ample evidence that green issues are quite relevant to the consumers across a wide cross-section of geographies, nationalities, and cultures. The second issue is regarding the choices that the consumers make in the wake of greening of the supply chains. A recent Boston Consulting Group report (BCG, 2009), which was based on a global study conducted with 9000 respondents across nine countries, states that the consumers are increasingly becoming concerned about the environmental effect of their consumption behavior. As a result, "green" has become a significant factor in where consumers shop and what they purchase. The BCG (2009) report mentions specifically that "…most of the consumers we spoke with consider a store's green credentials when choosing where to shop – a clear opportunity for savvy retailers." (p. 7). It is as if shopping green has become a way for consumers to act on their commitment to the environment. More than half of the consumers surveyed by BCG responded that they buy green products frequently. BCG report concluded that "There's no doubt that consumers all over the world are increasingly choosing in favor of green products." (p. 12). Although these preferences may vary across the product categories and perceived benefits by a particular consumer segment, it is clear that the above results provide strong evidence for the prevalence of the phenomenon of demand expansion due to greening efforts. It is therefore important that the analytical research stream addresses the rapidly emerging phenomenon of green supply chain management through specifically designed modeling efforts. The present paper is aimed at fulfilling this objective.

The rest of the paper is organized as follows. The next section provides the background literature for this paper. Section 3 discusses the model development and formulation. Section 4 provides the results of the various models. Section 5 presents the results of a representative numerical analysis. Section 6 concludes with the discussion and future research ideas.

2 Background Literature

This paper builds upon the following research streams.

2.1 Channel Coordination

Jeuland and Shugan (1983) define channel coordination as the setting of all manufacturer and retailer-related decision at the levels that would maximize total channel profits. In this context, the seminal work by McGuire and Staelin (1983) studied the impact of product substitutability on Nash equilibrium distribution structures where each manufacturer distributes its goods through an exclusive retailer. Jeuland and Shugan (1983) focused on channel coordination in the context of a single manufacturer and a single retailer structure. They find that coordination between a manufacturer and a retailer using a quantity discount schedule could lead to higher profit for channel members. Moorthy (1988) examines the effect of strategic interaction on a manufacturer's channel structure decisions.

Choi (1991) considers a channel structure consisting of two manufacturers and a single common retailer. His model addresses three types of games: the Manufacturer–Stackelberg game, the Retailer–Stackelberg game and Vertical–Nash equilibrium. Ingene and Parry (1995) took an opposite approach to Choi's (1991) and studied channel coordination by focusing on a single manufacturer using two competing retailers. They use a Stackelberg game, in which the manufacturer could apply either a two-part tariff scheme or a schedule for quantity discounts. They find that while quantity discount schedule facilitates channel coordination, the two-part tariff does not. Lee and Staelin (1997) provide a more generalized model allowing two manufacturers to interact with two retailers.

More recently, Arya and Mittendorf (2006) provided a counter-intuitive result that sometimes a separated, as opposed to vertically integrated, channel that embodies a degree of discord can be helpful from a long-term viewpoint. From the applications perspective, Raut et al. (2007) provide an innovative application of channel coordination in the motion picture industry characterized by a dynamic market environment, limited shelf space, product category management, and complex contractual practices They find that simpler contracts (e.g., two-part tariff, or 50/50 split of revenues) is sufficient to coordinate the movie channel considered.

2.2 Coordinating Green Supply Chains

Some research has begun to emerge in the area of the coordination of green supply chain. Goldbach, Seuring and Back (2003) provide a case study on the introduction of a sustainable cotton supply chain at a German mail-order business OTTO. The major difficulty arising in the chain was how to coordinate the activities of a complex network of different players involved in the chain. In the practical setting considered, the coordination required a set of hybrid approaches at different levels, ranging from market-like structures to hierarchical ones based on command-and-control mechanisms. Vachon and Klassen (2006) consider the impact of upstream and downstream integration on extending green practices across the supply chain. It was found that technological integration with primary suppliers and major customers was positively linked to environmental monitoring and collaboration. For logistical integration, a linkage was found only with environmental monitoring of suppliers. Mitra and Webster (2008) analyze a two-period model of a manufacturer who makes and sells a new product and a remanufacturer who competes with the manufacturer in the second period. They examine the effects of government subsidies as a means to promote remanufacturing activity. They find that the introduction of subsidies increases remanufacturing activity, and that the manufacturer’s profits generally decrease while the remanufacturer’s profits increase when 100% of the subsidy goes to the remanufacturer.

3 Conceptual Framework and Model Development

In this section, we begin with a broad-level conceptual framework aimed at understanding analytically the overall concept of GrSCM. Based on this framework, we then present a sub-section on model development.

3.1 Conceptual Framework

In this section, we explain the construct of GrSCM in terms of its antecedents and consequences. The antecedents or constituents of GrSCM have been reported extensively in prior literature. These are compiled nicely into a concise framework provided by

Srivastava (2007). Based on Srivastava's (2007) framework, the antecedents to GrSCM can be classified into the following categories: (i) Green Design, (ii) Green Manufacturing, (iii) Green remanufacturing, (iv) Reverse Logistics, (v) Waste management.

On the consequences side, there are some studies that have investigated the link between greening efforts by a firm and its economic performance. For example, Rao and Holt (2005) show that greening the different phases of a supply chain leads to an integrated supply chain which ultimately leads to better competitiveness and economic performance. However, virtually none of the studies has attempted to examine the constituents or source of this superior economic performance. In other words, it is not clear as to where the superior economic performance is coming from? Towards this end, we invoke the simple equation of profitability as a measure of economic performance:

Profit = (Price per unit – Cost per unit) * Quantity demanded

Based on the different elements of this equation that could be affected by the firm's greening effort, represented by the symbol τ, we can write the above equation as:

$$\pi(\tau) = [\, p(\tau) - c\,(\tau)] * Q\,(\tau) \tag{1}$$

where π, p, c, and Q denote total profit, price per unit, cost per unit, and quantity demanded, respectively. τ can be interpreted as an index of a firm's greening efforts.

This relationship gives rise to three consequences of greening efforts, which could lead to increased profits of a firm. The first consequence could be *price premium* that a firm could charge its consumers because of its greening efforts. This could be possible due to the positive image that a company builds as an environmentally-conscious concern. The second consequence could be *reduction in cost per unit*, which can be facilitated by effective green manufacturing and re-manufacturing efforts (e.g., reduction, recycling, refurbishing, reuse, etc.), as is addressed in SVW (2006). Finally, the third consequence could be *demand expansion*, which is specifically addressed in this paper, refers to the increase in quantity demanded of a firm's products as a result of its greening efforts.[2] The above discussion is summarized in Figure 1.

[2] To differentiate between the first and third consequences, while the price premium effect is meant to reflect the consumers' tendency to be willing to pay more for its greening efforts, the demand expansion

[Insert Figure 1 About Here]

3.2 Problem Formulation

There are several possible conflicts in a green supply chain. One major way in which the conflict could arise between could arise is the lack of commitment from either the supplier (at the upstream level) the retailer (at the downstream level) into the greening efforts by the manufacturer. This may be due to the differential incentives for the channel partners to invest in green practices. In this paper, we focus on this first kind of problem. The examples of the other kinds of conflicts include unwillingness of the supplier to exchange information with the manufacturer the effect of investments in greening efforts on price determination, competition among green suppliers, competition among green retailers, reverse channel design, and so on. Recent research has begun to address research issues in the coordination of green supply chain (Goldbach, Seuring and Back 2003; Vachon and Klassen 2006; Savaskan and van Wassenhove 2006; Mitra and Webster 2008, Walker et al. 2008).

The problem considered is of a single manufacturer who sells its products to a single retailer. Suppose the manufacturer puts in some effort for greening its operations, and the retailer also puts in a corresponding greening effort in retailing the product. The manufacturer makes decisions on the wholesale prices and its greening efforts, while the retailer makes decisions on the retail price and its corresponding greening efforts. We wish to examine the effect of various parameters, such as, price sensitivity, effectiveness of greening efforts, and cost of greening, etc. on the optimal pricing and efforts decisions by the channel partners. A noteworthy aspect of the problem situation considered in the current paper is that the demand of the product generated at the retail end is a function of the retail price and the greening efforts by *both* manufacturer and retailer. Thus, it may be in the interest of both the manufacturer and retailer to contribute jointly to this effect on profit generation.

3.3 Mathematical Model

We develop a mathematical model for the problem situation described above. Our model consists of a manufacturer, who, as a Stackelberg leader, decides first on a wholesale

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effect means that, given two manufacturers selling nearly identical product, a customer would be more will be willing to purchase the one that is more environment friendly. It is clear that the latter effect may arise independently of the relative prices of the products.

price w and a greening effort τ_m. Then, the retailer decides on the retail price p and its greening effort τ_r. The demand at the retailer is assumed to be downward sloping in retail price. Similar to SVW (2006), we assume that both the supply chain members have access to the same information while optimizing their objective functions, thus controlling for the issues resulting from information asymmetry. This simple supply chain structure is shown in Figure 2.

[Insert Figure 2 About Here]

To develop a model representing the demand expansion explanation of greening efforts, the demand at the retail end is considered as follows:

$$Q(p, \tau_r, \tau_m) = \theta - p + \alpha_{r1}\tau_r + \alpha_{m1}\tau_m \tag{2}$$

In this equation, θ represents market potential, and α_{r1} and α_{m1} represent the demand expansion effectiveness coefficients of the greening efforts by the retailer and manufacturer, respectively. The function in Equation 2 accounts for the *demand expansion effect* of the greening efforts by both manufacturer and retailer. This is represented by the greening indexes, τ_r and τ_m. The following profit functions are considered for the manufacturer and retailer, respectively:[3]

$$\pi_m = (w - c) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_m\tau_m^2 \tag{3}$$

$$\pi_r = (p - w - r) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_r\tau_r^2 \tag{4}$$

Some aspects of the cost of greening are in order here. Greening by retailer and manufacture requires upfront investment and is considered to be a function of greening effort τ. Similar to SVW (2006), we assume that upfront investment in greening is quadratic in nature, that is, investment $= \beta\,\tau^2$ where β is the green cost efficiency coefficient. Relatively higher value of β's would imply that firm is less efficient and

[3] The greening model presented assumes that greening initiative does not increase a firm's marginal cost. Of course, greening does entail fixed investment cost (not a function of quantity), which is quadratic in nature.

requires higher investment to achieve the same level of greening. Quadratic function implies that investment required in greening is convex in nature. Convex cost functions are often attributed to diminishing returns in process improvements in manufacturing (Fine and Porteus 1989), advertising and other promotion activities by retailers (Lilien et al. 1992), and R&D (Cohen and Klepper 1992).

4 Results

We first present the results of vertically integrated channel, and subsequently the results of a decentralized channel.

4.1 Integrated Channel

The total channel profits in this case are given by

$$\pi^I = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_r \tau_r + \alpha_m \tau_m) - \beta_r \tau_r^2 - \beta_m \tau_m^2 \tag{5}$$

Assuming concavity of the respective objective functions, the first-order conditions for π yield the optimal values of p, τ_r and τ_m, as shown below (refer Appendix for the complete derivation of results):

$$p^* = (c + r) + \frac{2\beta_r \beta_m}{(4\beta_r \beta_m - \beta_m \alpha_r^2 - \beta_r \alpha_m^2)} * (\theta - r - c) \tag{6}$$

$$\tau_r^* = \frac{\alpha_r \beta_m}{(4\beta_r \beta_m - \beta_m \alpha_r^2 - \beta_r \alpha_m^2)} * (\theta - r - c) \tag{7}$$

$$\tau_m^* = \frac{\beta_r \alpha_m}{(4\beta_r \beta_m - \beta_m \alpha_r^2 - \beta_r \alpha_m^2)} * (\theta - r - c) \tag{8}$$

4.2 Decentralized Channel

In this case, we present the result using the Stackelberg game structure. Assuming concavity of the respective objective functions, we first determine the best response functions of the retailer from the simultaneous solution of the first-order conditions of π_r. This gives π_r and p as functions of w and τ_m. These response functions are then used to derive an expression for π_m only in terms of the relevant decision variables at the manufacturer's level, that is, w and τ_m. The first-order conditions for π_m then yield the optimal values of w and τ_m, as shown below (refer Appendix for the complete derivation of results):

$$w^* = c + \frac{(4\beta_r\beta_m - \beta_m\alpha_r^2)}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{9}$$

$$\tau_m^* = \frac{\beta_r\alpha_m}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{10}$$

$$\tau_r^* = \frac{\alpha_r\beta_m}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{11}$$

$$p^* = (c + r) + \frac{(6\beta_r\beta_m - \beta_m\alpha_r^2)}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{12}$$

After the optimal values of the above variables have been inserted in Equations 3-4, we get the values of optimal manufacturer's and retailer's profits in the decentralized channel, denoted by π_m* and π_r*, respectively. The total channel profits in the decentralized channel are given by

$$\pi^D = \pi_m{*} + \pi_r{*} \tag{13}$$

There are some noteworthy aspects of the results shown in Equations 9-12. First, both w* and p* can be shown in terms of margin per unit. Thus, the expressions derived allow to represent results for (w*-c) and (p*-c-r). If presented in this form, the respective margins become functions of various greening parameters (e.g., α's and β's), and a term (θ-r-c). This latter term may be interpreted as "residual market potential" after accounting for cost of production and controlling or price sensitivity.[4]

Next, we define a term labeled as greening effectiveness coefficient for the manufacturer and the retailer, respectively, as the ratio of the square of their respective demand expansion effectiveness coefficient to the cost efficiency parameter. Greening effectiveness coefficient combines benefit in terms of demand effectiveness and cost

[4] For analytical convenience, no specific parameter has been chosen for price sensitivity factor in the demand function. It may be considered as 1 throughout the paper.

efficiency involved in greening effort. Because of the nature of the mathematical functions involved, this effectiveness coefficient plays a major role in determining the area of feasibility as well as performance comparisons across integrated and decentralized channel.

As shown in the appendix, to ensure feasibility of the results, we need to operate in the region bounded by following condition:

$$0 < \frac{\alpha_{\mathrm{r}}^2}{\beta_{\mathrm{r}}} + \frac{\alpha_{\mathrm{m}}^2}{\beta_{\mathrm{m}}} < 4$$

In the rest of the paper, we assume that the above feasibility conditions holds for all of our results. The feasibility condition itself is interesting as it suggests that, for feasibility, the sum of the greening effectiveness coefficients for the manufacturer and retailer should be bound from above. Such situations signify a distribution channel in which greening requires some degree of reasonable effort. It is important to note that feasibility condition does not place any condition on relative greening efficiency of the retailer or manufacturer. Within the overall bounds, there could be asymmetry in greening efficiency among retailer and manufacturer, that is, the manufacture can be more effective than the retailer in greening efforts, and vice-versa.

For the model considered, a specific relationship emerges between the optimal values of the greening efforts put in by the manufacturer and retailer, that is, τ_m* and τ_r*, respectively. This is summarized in the form of the following proposition:

Proposition 1: The ratio of the optimal greening efforts put in by the manufacturer and retailer, τ_m and τ_r*, respectively, is given by the following formula:*

$$\frac{\tau_m^*}{\tau_r^*} = \frac{\left(\frac{\alpha_m}{\alpha_r}\right)}{\left(\frac{\beta_m}{\beta_r}\right)} \tag{14}$$

The purport of Proposition 1 is as follows. If α's can be interpreted as the green sensitivity (demand expansion effectiveness) coefficient and β's as the green cost efficiency coefficient, then the ratio of the optimal greening efforts put in by the manufacturer and retailer is the ratio of their green sensitivity ratios and greening cost ratios. In other words, the manufacturer would be putting in more effort in greening the supply chain if either the market responsiveness to his efforts is greater than that of the retailer; or if the cost efficiency of greening for the manufacturer is lower than that of the retailer; or both.

It is interesting to note that Proposition 1 is valid in both of the cases of vertically integrated and decentralized channels. In other words, the ratio with which the manufacturer and retailer employ their greening efforts emerges in a coordinated manner even in a decentralized channel. However, the same cannot be said of the individual values of the respective greening efforts. As shown in the next section, as can be expected, the players put in more effort in the case of the integrated channel than in the case of decentralized channel.

4.3 Comparing the Results of Vertically Integrated and Decentralized Channels

We now compare various analytical results of the vertically integrated and decentralized channels. These are presented in the form of various propositions. The analytical values of the optimal results for various variables are shown in Table 1. Throughout the results, the superscript I denotes the 'integrated' channel, while D denotes the 'decentralized' channel.

[Insert Table 1 About Here]

Proposition 2: The following relation holds between the profits in the integrated channel and the decentralized channel: $\pi^I > 4/3\ \pi^D$.

Proposition 2 indicates that the total channel profits in the integrated channel will be significantly greater than that in the decentralized channel. This result is consistent with the earlier results in the channels literature. This shows that lack of coordination results in substantial loss in profitability. As we show later, the coordinated channel is able to ensure higher effort as well as more effective pricing decisions resulting in significantly higher profits for integrated chain. In integrated channel, profit increases by at least 33%. Thus, there is huge premium attached with the coordination of the green supply chain. This result implies that 33% is the lower bound on penalty for decentralization and the same increases steadily with increase in value of greening effectiveness coefficient. We now present the result regarding the prices.

Proposition 3: The following results are obtained:

$p^I = p^D$, if $\frac{\alpha_r^2}{\beta_r} + \frac{\alpha_m^2}{\beta_m} = 2$

$p^I > p^D$, if $\frac{\alpha_r^2}{\beta_r} + \frac{\alpha_m^2}{\beta_m} > 2$

$p^I < p^D$, if $\frac{\alpha_r^2}{\beta_r} + \frac{\alpha_m^2}{\beta_m} < 2$

Proposition 3 indicates that, if the following inequality holds: $\frac{\alpha_r^2}{\beta_r} + \frac{\alpha_m^2}{\beta_m} < 2$, then the retail price in the integrated channel will be lower than that in the decentralized channel. If the stated conditions hold, then this result is consistent with the earlier research in the channels literature, which has been termed as the ”double marginalization” issue in the distribution channels. Referring the demand term, it is clear that demand is affected by price as well as greening effort. This result suggests that, if the relative effectiveness of the greening efforts (relative to cost of greening) is below a certain threshold, then the integrated channel gets the desired demand expansion effect by lowering the retail prices. However, we find that if the opposite of the inequality holds, then the price in the integrated channel may be higher than that in the case of the decentralized channel.

The result suggests that if the relative effectiveness of the greening efforts is above a certain threshold, then the integrated channel may charge higher prices. This may be the case in those market segments in which there is considerable awareness and preference for green products. At the threshold value, both the integrated and decentralized channels price their products at the same level at the retailer’s end. Further, this behavior is not affected by asymmetry in greening effectiveness coefficients. Whether manufacture is more effective or retailer is more effective, pricing policy decisions are affected by sum of greening effectiveness coefficients of manufacturer and retailer.

Proposition 4: The ratio of the optimal greening efforts put in by the retailer in the integrated channel to that in decentralized channel is given by the following formula:

$$\frac{\tau_r^I}{\tau_r^D} = \frac{\Delta_1}{\Delta_2} = \frac{2\Delta_2 + \beta_r \alpha_m^2}{\Delta_2} > 2$$

Proposition 4 implies that, in the integrated channel, the retailers put in more than twice the effort of the retailer in decentralized channel. A similar relationship emerges for the manufacturer also. Optimal greening effort in the integrated channel is at least twice more than the effort observed in decentralized channel and the ratio of effort in integrated channel to the same in the decentralized channel increases steadily with increase in value of greening effectiveness coefficient. However, unlike pricing decisions, where the result is purely governed by the sum of the greening effectiveness coefficients and is not affected by asymmetry in greening effectiveness coefficients, as per Proposition 1, total relative efforts put in by manufacturer and retailer in a decentralized setup do get influenced by the relevant greening related parameters of the manufacturer and retailer, respectively.

Together, Propositions 2-4 indicate that, under certain condition, even in the presence of the greening efforts, the profits and efforts are higher in the case of integrated channel versus decentralized channel. However, the prices may be higher or lower in integrated effort depending on the value of greening effectiveness coefficients.

4.4 Additional Scenarios: When one or both of the parties do not put in greening effort

We replicate the above results for the following cases:

(i) When only manufacturer puts in the greening effort – In this case, the term τ_r and its coefficients were removed from the various expressions. The rest of the procedures were followed in the same manner as mentioned above in the context of integrated and decentralized channels.

(ii) When only retailer puts in the greening effort – In this case, the term τ_m and its coefficients were removed from the various expressions.

(iii) No greening effort – In this case, both of the terms τ_r and τ_m, and their relevant coefficients were removed from the various expressions. Thus, this case reduces to a pure vertical pricing game.

The analytical values of the optimal results for various variables in the above three cases are shown in Table 2.

[Insert Table 2 About Here]

4.4.1 When only manufacturer puts in the greening effort

We now provide the overall directionality of the analytical results in the following propositions.

Proposition 5A: When only the manufacturer puts in the greening effort, $\pi^I > 4/3\ \pi^{D,}$

Proposition 5A confirms the usual result that the profits in an integrated channel are greater than those in a decentralized channel. In this scenario, the results are similar to the case when both the manufacturer and retailer put in greening effort. Even in the current scenario, profit in the integrated channel increases by at least 33%, so there is huge premium in coordinating the green channel.

Proposition 5B: When only the manufacturer puts in the greening effort, and the following condition holds:

$$p^I = p^D, \text{ if } \frac{\alpha_m^2}{\beta_m} = 2$$

$$p^I > p^D, \text{ if } \frac{\alpha_m^2}{\beta_m} > 2$$

$$p^I < p^D, \text{ if } \frac{\alpha_m^2}{\beta_m} < 2$$

In this scenario, the results are similar to the case when both manufacturer and retailer put in greening effort.

Proposition 5C: When only the manufacturer puts in the greening effort, the ratio of the optimal greening efforts put in by the manufacturer in the integrated channel to that in the decentralized channel is given by the following formula:

$$\frac{\tau_r^I}{\tau_r^D} = 2 + \frac{\alpha_m^2}{(4\beta_m - \alpha_m^2)} > 2, \qquad \text{if} \quad \alpha_m^2 - 4\beta_m < 0.$$

Similar to Proposition 4, the above proposition implies that, in the integrated channel, the retailers put in more than twice the effort of the retailer in decentralized channel.

4.4.2 When only retailer puts in the greening effort

The analytical results are summarized in the following propositions.

Proposition 6A: When only the retailer puts in the greening effort, and the following condition holds, then $\pi^I = 4/3\ \pi^D$:

Proposition 5A confirms the usual result that the profits in an integrated channel have to be greater than a decentralized channel. However, unlike other scenarios, here, the penalty for decentralization does not change based on greening effectiveness coefficient. On this dimension, results observed in this scenario are very different from what we had observed in all other scenarios. In the other scenarios, the integrated set-up resulted in higher effort and different pricing decisions resulting in higher profits in integrated channel. As shown in proposition 6C, effort in greening is identical under integrated and decentralised channel. With a result integrated channel benefits from better pricing decision resulting 33% profit penalty observed in decentralized channel but since effort in greening remains same in integrated and decentralised set up, profit penalty remains at 33% irrespective of the value of greening effectiveness coefficient.

Proposition 6B: When only the retailer puts in the greening effort, the following condition holds

$p^I = p^D$, if $\frac{\alpha_r^2}{\beta_r} = 2$

$p^I > p^D$, if $\frac{\alpha_r^2}{\beta_r} > 2$

$p^I < p^D$, if $\frac{\alpha_r^2}{\beta_r} < 2$

In this scenario results are similar to the earlier case. Pricing policy in integrated and decentralized case is function of value of greening coefficients for manufacturer and retailer.

Proposition 6C: When only the retailer puts in the greening effort, the optimal greening effort in the integrated channel is equal to that in the decentralized channel, that is,

$$\tau_r^I = \tau_r^D$$

In this scenario results are very different from what we had observed in all other scenarios. Intuitively one would have expected higher effort in integrated channel, but as the results show there is no relative increase in greening effort in integrated channel. Of course as shown in proposition 6B, integrated channel results in better pricing decisions resulting in higher profits, But since greening effort remains same in integrated and decentralized channel, profit ratio between integrated channel and decentralised channel remains constant at 4/3. In the above, Propositions 6A and 6B yield similar results to the earlier cases, with appropriately modified conditions. Proposition 6C states that the greening efforts in both the integrated and decentralized cases. This is not surprising in view of the fact that in this case the greening effort is only being put at the retailer's end.

From the above results, we find that, under certain conditions of the parameters, we get the results similar to those reported earlier in the literature, namely, higher profits, and greater effort in the integrated channels as compared to the decentralized channel. *Interestingly, however, we find that, under certain conditions, optimal prices are higher in the integrated channel as compared to the case of the decentralized channel. This is not consistent with the usual 'double marginalization' explanation given in the channels literature.* In view of the lower profits in the decentralized case, therefore, the next pertinent question arises: *how to coordinate the green channel?*

4.5 Coordinating the Green Channel

In this section, we restrict our attention to the case in which both the manufacturer and the retailer put in the greening effort. In the previous literature, several approaches have been proposed for coordinating a distribution channel. These include quantity discounts (Jeuland and Shugan 1983), two-part tariff (Moorthy 1987), etc. In this paper, we propose a simple two-part pricing approach, (*F, w*), to coordinate the green channel in which there are both price and non-price variables. The procedure followed is as follows.

We assume that the per-unit wholesale price *w* charged by the manufacturer is the channel-coordinating price. In addition, the retailer makes a lump-sum payment *F* to the manufacturer. Under these assumptions, the profit functions for the manufacturer and retailer are:

$$\pi_m = (w - c) * (\theta - p + \alpha_r \tau_r + \alpha_m \tau_m) - \beta_m \tau_m^2 + F \quad (15)$$

$$\pi_r = (p - w - r) * (\theta - p + \alpha_r \tau_r + \alpha_m \tau_m) - \beta_r \tau_r^2 - F \quad (16)$$

Differentiating π_r with respect to p and τ_r, we get the first-order conditions for the retailer with expressions for p and τ_r as a function of *w*. Now, we use the expressions of

$p*$, τ_r^*, and τ_m^*, from the vertically-integrated case to get the values of w_c and F_c that would coordinate the green channel. The result is summarized in the following proposition (refer Appendix for proof).

Proposition 7: The following two-part tariff contract between the manufacturer and retailer coordinates the channel: $w_c = c$, *and* $0 \leq F < (p^*-r-c)^2$, *where p* is the optimal retail price in the integrated channel structure.*

This tariff structure suggests that the manufacturer would charge a wholesale price per unit which is just sufficient to recover its manufacturing cost per unit. Thus, it provides extra incentives to the retailer to charge lower retail prices and put in extra greening effort. The manufacturer boosts its profits from the fixed-fee component, which would be a result of negotiation between the retailer and manufacturer, in the limits provided by the proposition. The final value will be determined by the relative channel power that the manufacturer commands, which is not part of the model considered here. Since the upper limit on F_c has been derived as a result of the constraint that the retailer has to make non-zero profits, this negotiation process would make sure that both the manufacturer and retailer are "sharing the pie" appropriately.

5 Numerical Analysis

In this section, we present the results of a representative numerical analysis to explain some of the above results. The following parameter values were chosen. We set market potential θ, manufacturer cost c and retailer cost r at 100, 20 and 15, respectively throughout the numerical study. We study the impact of change in greening effectiveness coefficient on greening effort, price and profitability. The values of greening effectiveness coefficients for individual players are varied from starting value of 0.1 to the highest value of 1.9. This ensures that we operate within feasibility region. Value of β is maintained at 1 and values of α are worked out from the value of greening effectiveness coefficients. The results of our numerical analyses are presented in Figures 3 to 5.

[Insert Figures 3-5 About Here]

In the numerical analyses, we attempted to look at cases involving identical as well as dissimilar values of greening effectiveness coefficients across various players in the chain.[5] In Figures 3, 4 and 5, we compare the impact of change in value of total greening effectiveness coefficient on total effort, price and total profit respectively under integrated and decentralized set up. As expected, total effort and total profits are higher in integrated channel compared to decentralized set up. As the value of total greening effectiveness coefficient increases, the performance gap between integrated and decentralized channel widens. However, prices are lower in integrated channel compared to decentralized channel till the value of total greening effectiveness coefficient reaches value equal to two. Subsequently, at higher values of total greening effectiveness coefficient, prices in integrated channel are higher than prices observed in decentralized setting. It is interesting to observe that at higher values of total greening effectiveness coefficient (greater than 2), gaps for all the three measures, that is, total effort, prices and total profit between centralized and decentralized set up increases quite rapidly with increase in value of total greening effectiveness coefficient. This implies that at the higher levels of total greening effectiveness coefficient, the benefits from integration increase exponentially. Further benefits of integration are not driven by values of individual coefficients, but by values of total greening effectiveness coefficient.

In Figure 5, we study the impact of total greening effectiveness coefficient on retailer and manufacturer profitability respectively under decentralized channel. As shown in Figure 5, in the decentralized set up, relative share of retailer profit increases with increase in value of total greening effectiveness coefficient. That is, under the decentralized set up, with increase in value of total greening effectiveness coefficient, relative power of retailer goes up. This would have implications in deciding value of fixed fee in two part pricing contract discussed in Section 4.5.

6 Conclusions and Directions for Future Research

In this paper, we consider the problem of a single manufacturer who sells its products to a single retailer. The manufacturer puts in some effort for greening its operations, and the retailer also puts in a corresponding greening effort in retailing the product. The

[5] As far as the performance under the integrated chain is concerned, the values of individual parameters do not matter as long as the total effectiveness parameter (manufacturer greening effectiveness coefficient + retailer greening effectiveness coefficient) is maintained at same level. In the decentralized setup, results do change with dissimilar values of greening effectiveness coefficients across entities, but the changes are not substantial. Therefore, we restrict ourselves to reporting results with identical value of greening effectiveness coefficients across players in chain.

manufacturer makes decisions on the wholesale prices and its greening efforts, while the retailer makes decisions on the retail price and its corresponding greening efforts. The objective of our research was to derive equilibrium conditions for the variables considered. We assumed the manufacturer to be the leader in the Stackelberg leader-follower game setting. We examined the effect of various parameters, such as, effectiveness of greening efforts, cost of greening, etc. on the optimal pricing and efforts decisions by the channel partners.

Our major results show that: (i) The ratio of the optimal greening efforts put in by the manufacturer and retailer is the ratio of their green sensitivity ratios and greening cost ratios. This result holds irrespective of whether it is an integrated or a decentralized channel, (ii) Under certain conditions, the optimal prices are lower, profits are higher and efforts are higher in the integrated channel as compared to the case of the decentralized channel. This is consistent with the earlier research in the channels literature, (iii) Interestingly, however, we find that, under certain conditions, optimal prices are higher, and profits are lower in the integrated channel as compared to the case of the decentralized channel. This is not consistent with the usual 'double marginalization' explanation given in the channels literature, (iv) By and large, the above results replicate themselves in the cases in which only one of the two channel members (i.e., either manufacturer or retailer) puts in the greening effort, (v) A two-part tariff contract from the manufacturer and retailer, which takes into account the relevant parameters of prices and greening efforts, can produce the desired effect of channel coordination in this problem. The numerical analysis results corroborate some of the above results.

This work can be extended into several directions, which are listed below: (i) We can also model the greening effects of cost reduction and price premium into this framework, (ii) The consideration of multiple manufacturers and retailers would provide additional useful insights, and (iii) The incorporation of uncertainty, unobservability of efforts, and dynamics would provide even richer results in this framework.

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Figure 1: Antecedents and Consequences of Green Supply Chain Management

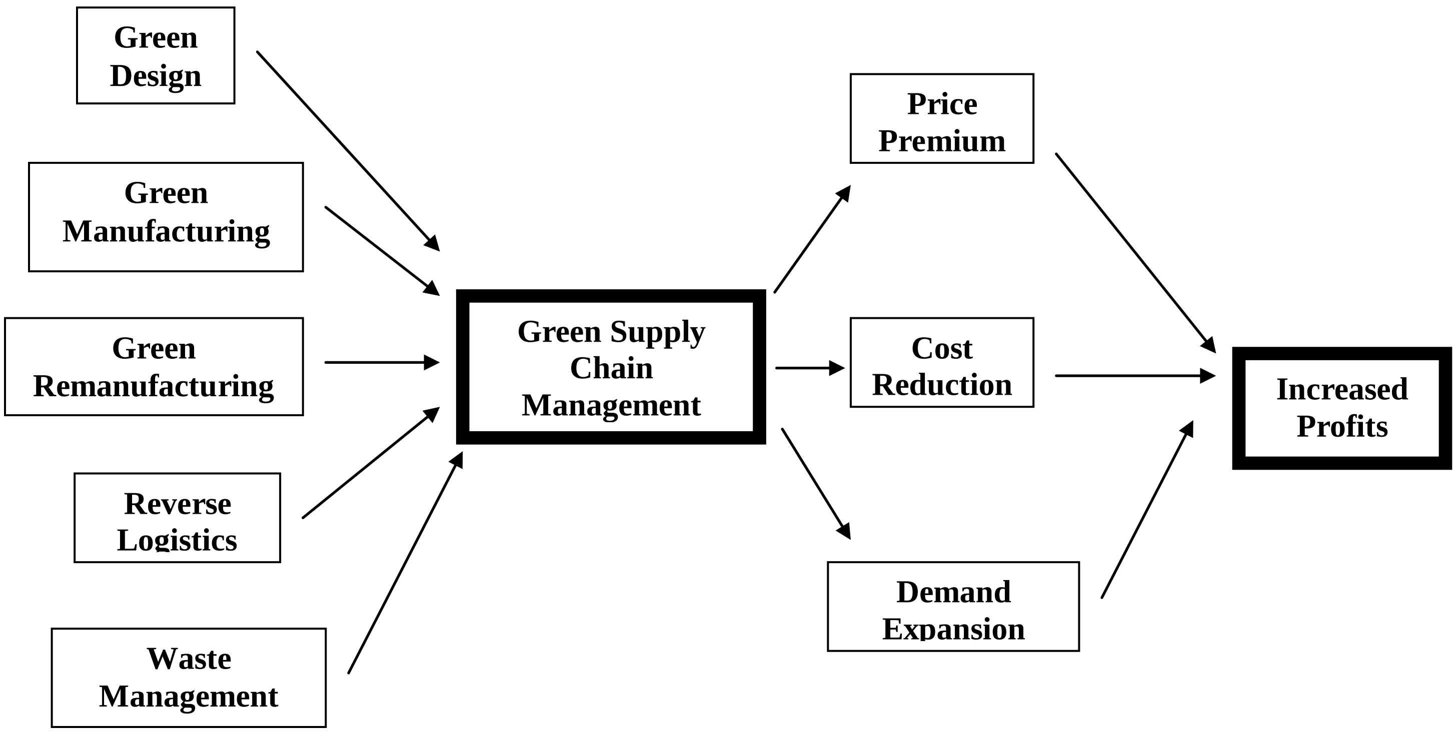

Figure 2: Structure of the Supply Chain Considered

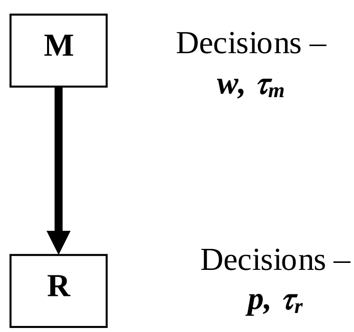

Figure 3: Graph of Total Effort versus the ratio ($\alpha_r^2/\beta_r + \alpha_m^2/\beta_m$) in Integrated (I) and Decentralized (D) Channels

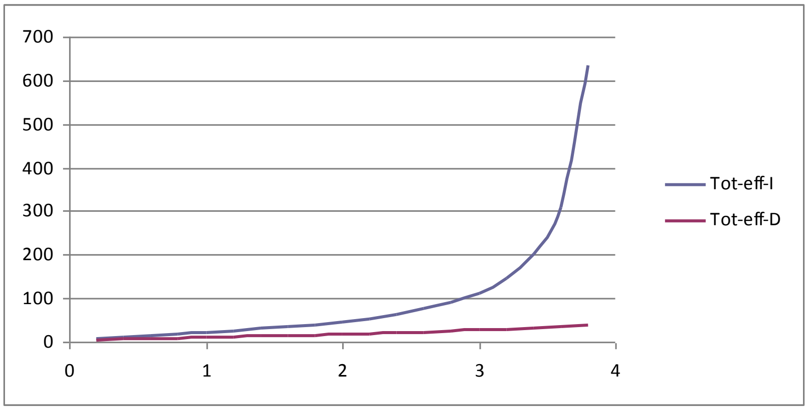

Figure 4: Graph of Price versus the ratio ($\alpha_r^2/\beta_r + \alpha_m^2/\beta_m$) in Integrated (I) and Decentralized (D) Channels

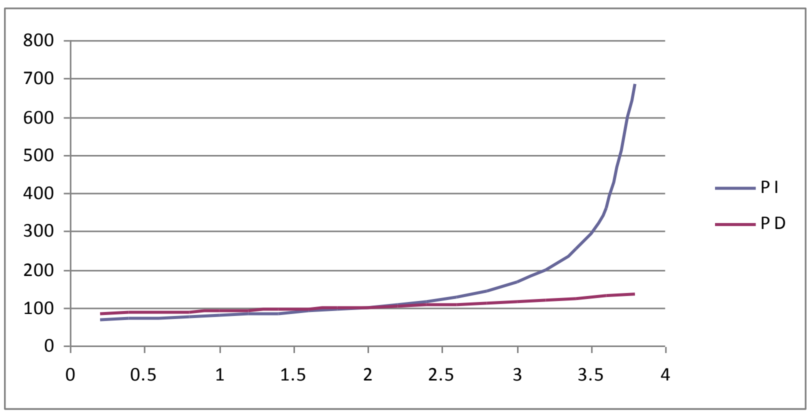

Figure 5: Graph of Profit versus the ratio ($\alpha_r^2/\beta_r + \alpha_m^2/\beta_m$) in Integrated (I) and Decentralized (D) Channels

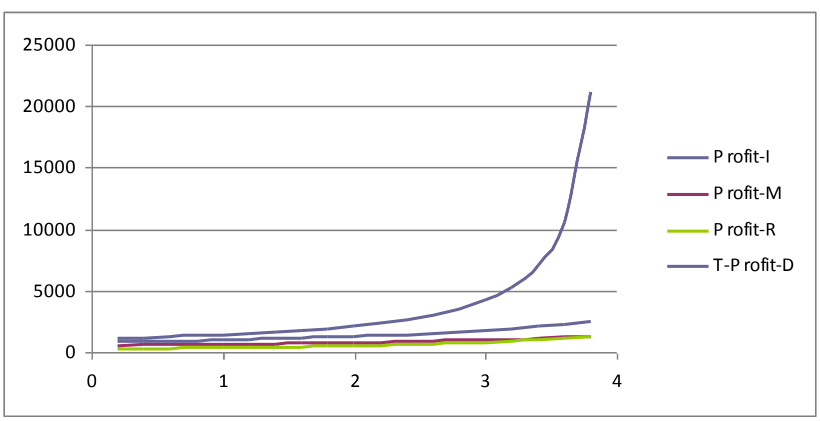

Table 1: Comparison of Analytical Results for Decentralized and Integrated Channels:
When Both Manufacturer and Retailer Put in Effort in Greening the Supply Chain

parison easure	Decentralized	Integrated
Profit	$\pi^D = \left(\frac{\theta-r-c}{\Delta_1}\right)^2 * (12\beta_r^2\beta_m^2 - 3\beta_r\beta_m^2\alpha_r^2 - \beta_m\beta_r^2\alpha_m^2)$	$\pi^{I*} = \frac{\beta_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)^2$
olesale price	$w^* = c + \frac{(4\beta_r\beta_m - \beta_m\alpha_r^2)}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$	--
ail price	$p^* = (c + r) + \frac{(6\beta_r\beta_m - \beta_m\alpha_r^2)}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$	$p^* = (c + r) + \frac{2\beta_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r$
facturer's ffort	$\tau_m^* = \frac{\beta_r\alpha_m}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$	$\tau_m^* = \frac{\beta_r\alpha_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$
tailer's ffort	$\tau_r^* = \frac{\alpha_r\beta_m}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$	$\tau_r^* = \frac{\alpha_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$

Table 2: Comparison of Analytical Results for Decentralized and Integrated Channels:
When Only One or Neither of the Players Puts in Effort in Green Supply Chain

(A) Only Manufacturer's Effort

parison easure	Decentralized	Integrated
Profit	$\pi^{D*} = \frac{12\beta_m^2 - \beta_m\alpha_m^2}{(8\beta_m - \alpha_m^2)^2} * (\theta - r - c)^2$	$\pi^{I*} = \frac{\beta_m}{(4\beta_m - \alpha_m^2)} * (\theta - r - c)^2$
olesale price	$w^* = c + \frac{4\beta_m}{(8\beta_m - \alpha_m^2)} * (\theta - r - c)$	--
ail price	$p^* = (c + r) + \frac{6\beta_m}{(8\beta_m - \alpha_m^2)} * (\theta - r - c)$	$p^* = (c + r) + \frac{2\beta_m}{(4\beta_m - \alpha_m^2)} * (\theta - r - c)$
facturer's ffort	$\tau_m^* = \frac{\alpha_m}{(8\beta_m - \alpha_m^2)} * (\theta - r - c)$	$\tau_m^* = \frac{\alpha_m}{(4\beta_m - \alpha_m^2)} * (\theta - r - c)$

Table 2: Comparison of Analytical Results for Decentralized and Integrated Channels:
When Only One or Neither of the Players Puts in Effort in Green Supply Chain

(B) Only Retailer's Effort

parison easure	**Decentralized**	**Integrated**
Profit	$\pi^{D*} = \frac{3\beta_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})^2$	$\pi^{I*} = \frac{4\beta_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})^2$
olesale price	$w^* = c + \left(\frac{\theta - r - c}{2}\right)$	--
ail price	$p^* = (c + r) + \frac{6\beta_r - \alpha_r^2}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})$	$p^* = (c + r) + \frac{4\beta_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})$
tailer's ffort	$\tau_r^* = \frac{\alpha_r}{(4\beta_r - \alpha_r^2)} * \left(\frac{\theta - r - c}{2}\right)$	$\tau_r^* = \frac{\alpha_r}{(4\beta_r - \alpha_r^2)} * \left(\frac{\theta - r - c}{2}\right)$

Table 2: Comparison of Analytical Results for Decentralized and Integrated Channels:
When Only One or Neither of the Players Puts in Effort in Green Supply Chain

(C) No Effort Case

parison easure	Decentralized	Integrated
rofit	$\pi^{D*} = \frac{3}{16} * (\theta - r - c)^2$	$\pi^{I*} = \frac{1}{4} * (\theta - r - c)^2$
olesale price	$w^* = c + \frac{1}{2} * (\theta - r - c)$	--
ail price	$p^* = (c + r) + \frac{3}{4} * (\theta - r - c)$	$p^* = (c + r) + \frac{1}{2} * (\theta - r - c)$

Appendix:
Channel Coordination in Green Supply Chain Management

Decentralized Channel

$$\pi_m = (w - c) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_m\tau_m^2 \tag{A.1}$$

$$\pi_r = (p - w - r) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_r\tau_r^2 \tag{A.2}$$

Assuming concavity of the respective objective functions, we first determine the best response functions of the retailer from the simultaneous solution of the first-order conditions of π_r. This gives π_r and p as functions of w and τ_m.

$$\frac{\partial\pi_r}{\partial p} = 0 \quad \rightarrow \quad 2p = \theta + w + r + \alpha_r\tau_r + \alpha_m\tau_m \tag{A.3}$$

$$\frac{\partial\pi_r}{\partial\tau_r} = 0 \quad \rightarrow \quad \alpha_r(p - w - r) - 2\beta_r\tau_r = 0 \tag{A.4}$$

These response functions are then used to derive an expression for π_m only in terms of the relevant decision variables at the manufacturer's level, that is, w and τ_m. This yields the following expression:

$$\pi_m = (w - c) * (\frac{2\beta_r}{(4\beta_r - \alpha_r^2)})(\theta - w - r + \alpha_m\tau_m) - \beta_m\tau_m^2 \tag{A.5}$$

This implies a condition that $\left(\frac{2\beta_r}{(4\beta_r - \alpha_r^2)}\right) > 0$, or $(4\beta_r - \alpha_r^2) > 0$. (A.6)

The first-order conditions for π_m then yield the optimal values of w and τ_m, as shown below:

$$w^* = c + \frac{(4\beta_r\beta_m - \beta_m\alpha_r^2)}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{A.7}$$

$$\tau_m^* = \frac{\beta_r\alpha_m}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{A.8}$$

When used in Equations A.6 and A.7, we get

$$\tau_r^* = \frac{\alpha_r\beta_m}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{A.9}$$

$$p^* = (c+r) + \frac{(6\beta_r\beta_m - \beta_m\alpha_r^2)}{(8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$$

(A.10)

We define $\Delta_1 = 8\beta_r\beta_m - 2\beta_m\alpha_r^2 - \beta_r\alpha_m^2$.

The total profit of the decentralized channel is given by

$\pi^D = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_r\tau_r^2 - \beta_m\tau_m^2$,

where the values of optimized variables come from Equations A.7 – A.10. Inserting these values, we get

$$\pi^D = \left(\frac{\theta - r - c}{\Delta_1}\right)^2 * (12\beta_r^2\beta_m^2 - 3\beta_r\beta_m^2\alpha_r^2 - \beta_m\beta_r^2\alpha_m^2)$$

(A.11)

Integrated Channel

$\pi^I = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_r\tau_r^2 - \beta_m\tau_m^2$ (A.12)

Assuming concavity of the respective objective functions, the first-order conditions with respect to p, τ_r and τ_m give:

$$p^* = (c+r) + \frac{2\beta_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$$

(A.13)

$$\tau_r^* = \frac{\alpha_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$$

(A.14)

$$\tau_m^* = \frac{\beta_r\alpha_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$$

(A.15)

Based on A.13, we define a feasibility condition as follows:

$$p^* - c - r = \frac{2}{(4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m})} * (\theta \text{ - } r\text{-}c) > 0$$

Thus, $(4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m}) > 0$

or $4 > \frac{\alpha_r^2}{\beta_r} + \frac{\alpha_m^2}{\beta_m}$

Further, we define $\Delta_2 = 4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2$

The total profit of the integrated channel is given by

$\pi^I = (p - r - c) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_r\tau_r^2 - \beta_m\tau_m^2$,

where the values of optimized variables come from Equations A.13 – A.15. Inserting these values, we get

$$\pi^I = (\theta - r - c)^2 * \frac{\beta_r\beta_m}{\Delta_2} \tag{A.16}$$

Proof of Proposition 1: Equations A.8 and A.9 give the condition

$$\frac{\tau_m^*}{\tau_r^*} = \frac{\left(\frac{\alpha_m}{\alpha_r}\right)}{\left(\frac{\beta_m}{\beta_r}\right)}$$

Proof of Proposition 2: Equations A.11 and A.16 give the relation

$$\frac{\pi^I}{\pi^D} = \frac{\Delta_1^2}{\Delta_2 * \left(12\beta_r\ \beta_m - 3\beta_m\alpha_r^2 - \beta_r\ \alpha_m^2\right)} \tag{A.17}$$

$$= \frac{\left(8\beta_r\ \beta_m - 2\beta_m\alpha_r^2 - \beta_r\ \alpha_m^2\right)^2}{\left(4\beta_r\ \beta_m - \beta_m\alpha_r^2 - \beta_r\ \alpha_m^2\right) * \left(12\beta_r\ \beta_m - 3\beta_m\alpha_r^2 - \beta_r\ \alpha_m^2\right)}$$

This can be transformed to

$$= \frac{(8 - 2\alpha_r^2/\beta_r - \alpha_m^2/\beta_m)^2}{\frac{3}{4}(8 - 2\alpha_r^2/\beta_r - \alpha_m^2/\beta_m)^2 - \alpha_m^2/\beta_m(4 - \alpha_r^2/\beta_r - \alpha_m^2/4\beta_m)}$$

As per the feasibility condition, $\alpha_m^2/\beta_m(4 - \alpha_r^2/\beta_r - \alpha_m^2/4\beta_m) > 0$, therefore,

$$\frac{\pi^I}{\pi^D} > \frac{(8 - 2\alpha_r^2/\beta_r - \alpha_m^2/\beta_m)^2}{\frac{3}{4}(8 - 2\alpha_r^2/\beta_r - \alpha_m^2/\beta_m)^2}$$

$$\frac{\pi^I}{\pi^D} > \frac{4}{3}$$

Proof of Proposition 3:

$$p^I = (c + r) + \frac{2\beta_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c)$$

$$\frac{p^I - c - r}{(\theta\text{ - }r\text{-}c)} = \frac{2}{(4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m})}$$

Similarly,

$$\frac{p^D - c - r}{(\theta\text{ - }r\text{-}c)} = \frac{(6 - \frac{\alpha_r^2}{\beta_r})}{(8 - 2\frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m})} = \frac{(4 - \frac{\alpha_r^2}{\beta_r} + 2)}{(4 - \frac{\alpha_r^2}{\beta_r} + 4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m})}$$

From the above, it is clear that

$p^I = p^D$, when $(4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m}) = 2$, or

$p^I < p^D$, when $(4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m}) > 2$, or $\frac{\alpha_\mathrm{r}^2}{\beta_\mathrm{r}} + \frac{\alpha_\mathrm{m}^2}{\beta_\mathrm{m}} < 2$

$p^I > p^D$, when $(4 - \frac{\alpha_r^2}{\beta_r} - \frac{\alpha_m^2}{\beta_m}) < 2$, or $\frac{\alpha_\mathrm{r}^2}{\beta_\mathrm{r}} + \frac{\alpha_\mathrm{m}^2}{\beta_\mathrm{m}} > 2$

Proof of Proposition 4: It is evident from the main text and the derivation of general results given in Equations A.1-A.16.

For Proposition 5: When only manufacturer puts in the greening effort

Decentralized Case:

$\pi_r = (p - w - r) * (\theta - p + \alpha_m\tau_m)$ (A.18)

$\frac{\partial\pi_r}{\partial p} = 0 \quad \rightarrow \quad 2p = \theta + w + r + \alpha_m\tau_m$ (A.19)

$\pi_m = (w - c) * (\theta - p + \alpha_m\tau_m) - \beta_m\tau_m^2$ (A.20)

Putting A.19 into A.20, we get

$$\pi_m = (w - c) * (\frac{1}{2} * (\theta - w - r + \alpha_m\tau_m) - \beta_m\tau_m^2$$

The first-order conditions for π_m then yield the optimal values of w and τ_m, as shown below:

$$w^* = c + \frac{4\beta_m}{(8\beta_m - \alpha_m^2)} * (\theta - r - c)$$

(A.21)

$$\tau_m^* = \frac{\alpha_m}{(8\beta_m - \alpha_m^2)} * (\theta - r - c)$$

(A.22)

When used in Equation A.19, we get

$$p^* = (c + r) + \frac{6\beta_m}{(8\beta_m - \alpha_m^2)} * (\theta - r - c)$$

(A.23)

The total profit of the decentralized channel is given by

$\pi^D = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_m \tau_m) - \beta_m \tau_m^2$,

where the values of optimized variables come from Equations A.21 – A.23. Inserting these values, we get

$$\pi^D = (\theta - r - c)^2 * \left(\frac{12\beta_m^2 - \beta_m \alpha_m^2}{(8\beta_m - \alpha_m^2)^2}\right)$$

(A.24)

Integrated Channel:

$$\pi^I = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_m \tau_m) - \beta_m \tau_m^2 \qquad \text{(A.25)}$$

The first-order conditions with respect to p and τ_m give:

$$p^* = (c + r) + \frac{2\beta_m}{(4\beta_m - \alpha_m^2)} * (\theta - r - c)$$

(A.26)

$$\tau_m^* = \frac{\alpha_m}{(4\beta_m - \alpha_m^2)} * (\theta - r - c)$$

(A.27)

The total profit of the integrated channel is given by

$\pi^I = (p - r - c) * (\theta - p + \alpha_m \tau_m) - \beta_m \tau_m^2$,

where the values of optimized variables come from Equations A.26 – A.27. Inserting these values, we get

$$\pi^I = (\theta - r - c)^2 * \frac{\beta_m}{(4\beta_m - \alpha_m^2)}$$

(A.28)

Proof of Proposition 5A:

$$\frac{\pi^I}{\pi^D} = \frac{\frac{\beta_m}{(4\beta_m - \alpha_m^2)}}{(\frac{12\beta_m^2 - \beta_m\alpha_m^2}{(8\beta_m - \alpha_m^2)^2})}$$

(A.29)

This can be transformed to

$$= \frac{(8 - \alpha_m^2/\beta_m)^2}{\frac{3}{4}(8 - \alpha_m^2/\beta_m)^2 - \alpha_m^2/\beta_m(4 - \alpha_m^2/4\beta_m)}$$

As per the feasibility condition, $\alpha_m^2/\beta_m(4 - \alpha_m^2/4\beta_m) > 0$, therefore,

$$\frac{\pi^I}{\pi^D} > \frac{(8 - \alpha_m^2/\beta_m)^2}{\frac{3}{4}(8 - \alpha_m^2/\beta_m)^2}$$

$$\frac{\pi^I}{\pi^D} > \frac{4}{3}$$

Proof of Proposition 5B:

$$\frac{p^I - c - r}{(\theta\text{ - }r\text{-}c)} = \frac{2}{(4 - \frac{\alpha_m^2}{\beta_m})}$$

$$\frac{p^D - c - r}{(\theta\text{ - }r\text{-}c)} = \frac{6}{(8 - \frac{\alpha_m^2}{\beta_m})} = \frac{(4+2)}{(4 + 4 - \frac{\alpha_m^2}{\beta_m})}$$

From the above, it is clear that

$p^I = p^D$, when $(4 - \frac{\alpha_m^2}{\beta_m}) = 2$, or $\frac{\alpha_m^2}{\beta_m} = 2$

$p^I < p^D$, when $(4 - \frac{\alpha_m^2}{\beta_m}) > 2$, or $\frac{\alpha_m^2}{\beta_m} < 2$

$p^I > p^D$, when $(4 - \frac{\alpha_m^2}{\beta_m}) < 2$, or $\quad \frac{\alpha_m^2}{\beta_m} > 2$

Proof of Proposition 5C: It is evident from the main text itself.

For Proposition 6: When only retailer puts in the greening effort

Decentralized Case:

$$\pi_r = (p - w - r) * (\theta - p + \alpha_r \tau_r) - \beta_r \tau_r^2 \tag{A.30}$$

$$\frac{\partial \pi_r}{\partial p} = 0 \quad \rightarrow \quad 2p = \theta + w + r + \alpha_r \tau_r \tag{A.31}$$

$$\frac{\partial \pi_r}{\partial \tau_r} = 0 \quad \rightarrow \quad \alpha_r (p - w - r) - 2\beta_r \tau_r = 0 \tag{A.32}$$

$$\pi_m = (w - c) * (\theta - p + \alpha_r \tau_r) \tag{A.33}$$

Putting A.31 and A.32 into A.33, we get

$$\pi_m = (w - c) * (\frac{2\beta_r}{(4\beta_r - \alpha_r^2)}) * (\theta - w - r)$$

The first-order conditions for π_m then yield the optimal values of w, as shown below:

$$w^* = c + (\frac{\theta - r - c}{2}) \tag{A.34}$$

When used in Equations A.31 and A.32, we get

$$\tau_r^* = \frac{\alpha_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2}) \tag{A.35}$$

$$p^* = (c + r) + \frac{(6\beta_r - \alpha_r^2)}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2}) \tag{A.36}$$

The total profit of the decentralized channel is given by

$\pi^D = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_r \tau_r) - \beta_r \tau_r^2,$

where the values of optimized variables come from Equations A.34 – A.36. Inserting these values, we get

$$\pi^{D*} = \frac{3\beta_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})^2 \tag{A.37}$$

Integrated Channel:

$$\pi^I = \pi_r + \pi_m = (p - r - c) * (\theta - p + \alpha_r \tau_r) - \beta_r \tau_r^2 \tag{A.38}$$

The first-order conditions with respect to p and τ_r give:

$$p^* = (c + r) + \frac{4\beta_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})$$

(A.39)

$$\tau_r^* = \frac{\alpha_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})$$

(A.40)

The total profit of the integrated channel is given by

$$\pi^I = \quad (p - r - c) * (\theta - p + \alpha_r \tau_r) - \beta_r \tau_r^2$$

where the values of optimized variables come from Equations A.39 – A.40. Inserting these values, we get

$$\pi^{I*} = \frac{4\beta_r}{(4\beta_r - \alpha_r^2)} * (\frac{\theta - r - c}{2})^2 \tag{A.41}$$

Proof of Proposition 6A:

From A.37 and A.41, it is clear that

$$\frac{\pi^I}{\pi^D} = \frac{4}{3}$$

(A.42)

Proof of Proposition 6B:

The proof is similar to that of Proposition 5B.

Proof of Proposition 6C: It is evident from the expressions A.35 and A.40.

Proof of Proposition 7:

The profit functions for manufacturer and retailer are given by

$$\pi_m = (w - c) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_m\tau_m^2 + F \tag{A.43}$$

$$\pi_r = (p - w - r) * (\theta - p + \alpha_r\tau_r + \alpha_m\tau_m) - \beta_r\tau_r^2 - F \tag{A.44}$$

Assuming concavity of the respective objective functions, we first determine the best response functions of the retailer from the simultaneous solution of the first-order conditions of π_r. This gives π_r and p as functions of w and τ_m.

$$\frac{\partial\pi_r}{\partial p} = 0 \quad \rightarrow \quad 2p = \theta + w + r + \alpha_r\tau_r + \alpha_m\tau_m \tag{A.45}$$

$$\frac{\partial\pi_r}{\partial\tau_r} = 0 \quad \rightarrow \quad \alpha_r(p - w - r) - 2\beta_r\tau_r = 0 \tag{A.46}$$

From the vertically integrated case (Equations A.13-A.15) we know the following:

$$p^* = (c + r) + \frac{2\beta_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{A.47}$$

$$\tau_r^* = \frac{\alpha_r\beta_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{A.48}$$

$$\tau_m^* = \frac{\beta_r\alpha_m}{(4\beta_r\beta_m - \beta_m\alpha_r^2 - \beta_r\alpha_m^2)} * (\theta - r - c) \tag{A.49}$$

Putting these values in A.45 and A.46, and extensively simplifying, we get:

w*= per-unit transfer price = c (A.50)

Putting the values from A.47-A.50 into A.44, we get

$$\pi_r = (p - r - c) * \left(\theta - p + \frac{\alpha_r^2\beta_m}{\Delta_2}(\theta - r - c) + \frac{\alpha_m^2\beta_r}{\Delta_2}(\theta - r - c)\right)$$
$$- \beta_r\left[\frac{\alpha_r\beta_m}{\Delta_2} * (\theta - r - c)\right]^2 - F$$

After putting in the value of p*, this simplifies to

$$\pi_r = (p^* - r - c)^2 - F$$

Since retailer has to make some profit, we have

$(p^* - r - c)^2 - F > 0$, or $\quad F < (p^* - r - c)^2$

(A.51)