"BEHAVIOURAL INSIGHTS IN GREENING DECISIONS UNDER COBB DOUGLAS DEMAND: EXPLORING OVERCONFIDENCE IN CENTRALIZED AND DECENTRALIZED SUPPLY CHAINS"

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Abstract. This study explores how a manufacturer's overconfidence can shape decision-making strategies and overall performance in green supply chains, especially in the context of growing global demand for sustainable practices. Departing from the traditional assumption of rational behaviour, it introduces behavioural bias into supply chain modeling to understand how inflated perceptions of greening investment efficiency influence outcomes. Demand is sensitive to both greening and price, captured through a Cobb–Douglas-type differential demand function. The research seeks to bridge behavioural operations management with sustainability-focused supply chain design. The paper employs a Stackelberg game-theoretic framework where the retailer acts as the leader, setting the retail price, and the manufacturer acts as the follower, choosing the greening effort and wholesale price. The model is categorized under two structures centralized and decentralized decision-making structures. Overconfidence is mathematically modeled as an upward bias in the manufacturer's perception of greening return. Analytical expressions for equilibrium decisions and profits are derived, comparing outcomes under both rational and overconfident scenarios. The analysis reveals that overconfidence does not change the optimal decision values. However, it increases profit for both the manufacturer and retailer and the market demand. This counterintuitive result emerges because the overconfident manufacturer invests more in greening, which enhances perceived sustainability and thus attracts more consumers. The model shows that behavioural bias—often considered a liability—can, under certain conditions, improve overall supply chain performance.

Implication of Study: The findings provide novel managerial and theoretical insights. From a behavioural operations perspective, the results show that mild overconfidence can be beneficial, leading to higher profits and sustainability without requiring changes to contract structures. It highlights the value of integrating behavioural traits into green supply chain models, especially when designing incentive- compatible contracts.

This contributes to the

developing field of behavioural green supply chain management, offering a foundation for future research that blends cognitive bias, sustainability, and decentralized decision-making under uncertainty.
Keyword: Green Supply Chain, Overconfidence, Differential Demand, Cobb-Douglas Demand, Stackelberg Game

INTRODUCTION

In the last few years, the design of sustainable and environmentally responsible operations has become a core concern in green supply chain management, providing growth to the concept of green supply chains. Day by day the green supply chain is a rapidly growing topic in both academia and industry (Ma et al., 2024; Fahimnia et al., 2015; Ghosh and Shah, 2012). Green supply chains have been widely studied as mechanisms to integrate environmental concerns into traditional supply chain operations, particularly through greening investments and eco- friendly practices (Li & Shan, 2023; Srivastava et al., 2022). A green supply chain integrates environmental considerations—such as greening investments, carbon reduction, and eco-friendly practices—into traditional logistics and production decisions.

Overconfidence is a belief that a decision-maker's knowledge is more valuable or precious than reality (Camerer & Lovallo, 1999; Fahimnia, Pournader, Siemsen, Bendoly, & Wang, 2019; Li, 2019), While classical models assume rational decision-making, growing evidence suggests that behavioural factors, especially overconfidence, play a significant role in shaping managerial choices. Overconfidence may cause decision makers to systematically overestimate the benefits of greening efforts, thereby influencing both prices and investment levels in unexpected ways. Beyond fairness concern, overconfidence is another commonly explored form of irrational behaviour. Psychological studies have shown that individuals often show excessive overconfident in real world economic (Moore & Healy, 2008). So, in this context, overconfidence is a belief that a decision-maker's knowledge is more valuable or precious than reality (Liu, Shen, & Wang, 2018).

To better reflect the complexity of demand in such contexts, many studies have employed differential demand structures, which allow demand to be jointly influenced by prices, greening levels, and other market signals. Among these approaches, the Cobb–Douglas demand model provides a particularly flexible and analytically. Such demand functions is widely applied in the economics, operations management, and marketing literature (Ma et al.,2013; Moon et al.,2018; Wang et al.,2013). By capturing both price sensitivity and greening responsiveness in multiplicative form, it provides a useful tool to analze how overconfident perceptions of greening efforts reshape demand outcomes and, consequently, profitability across the supply chain.

Decision- making structures play a crucial role in supply chain outcomes. In centralized supply chains, the manufacturer and retailer cooperate to maximize total profit of the system, on the other hand in decentralized supply chains, each party pursues individual optimization, often leading to inefficiencies. To bridge these contrasting setups, game-theoretic models such as the Stackelberg game are widely applied (Cachon, 2003). In this hierarchical framework, one party (often the retailer) assumes a leadership role by setting retail prices, while the manufacturer responds with decisions on wholesale pricing and greening investment. The presence of overconfidence in such Stackelberg interactions creates new dynamics that affect equilibrium outcomes in both centralized and decentralized contexts.

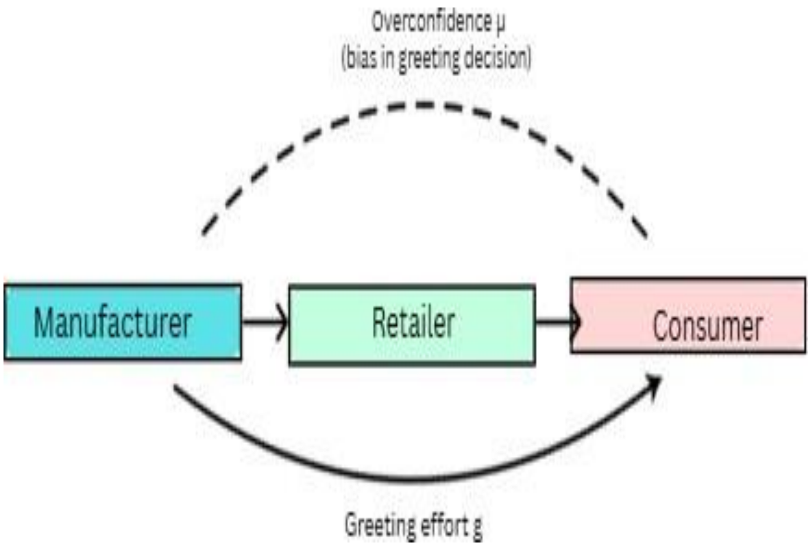
This paper investigates how behavioral biases— specifically overconfidence— interact with Cobb– Douglas differential demand structures in green supply chains, comparing results under centralized and decentralized decision frameworks. By embedding these considerations within a Stackelberg game setting, the study seeks to uncover novel insights into how cognitive biases influence optimal strategies, market demand, and profitability. The findings contribute to both theory and practice by extending the literature on behavioral operations and offering guidance for sustainable supply chain contract design in uncertain and behaviorally influenced environments.

Most existing research assumes fully rational firms. In reality, firms often display behavioral biases, especially overconfidence in the returns from greening investments. This study aims to find the answers to the following research questions:

- What are the comparative effects of centralized and decentralized decision- making on profits, demand, and greening effort under overconfidence?
- Can overconfidence mitigate the inefficiencies of decentralized structures?
- How does manufacturer overconfidence regarding greening returns affect optimal price, wholesale price, and greening effort in a supply chain governed by Cobb– Douglas demand?

None of researchers have worked on a Cobb Douglas demand with overconfidence in greening and Stackelberg game approaches to understand their impact on pricing, greening decisions, demand and overall supply chain performance using centralized and decentralized approaches. This paper consists of section 1, the introduction and literature review. Section 2 consists of notations and assumptions. Section 3 consists of mathematical formulation, centralized and decentralized model. section4 consists of numerical and sensitivity analysis. Section 5 consists of the conclusion.

Figure1 Green supply chain



Notations And Assumptions

Following are the assumptions and notation given below in Table 1.

Table 1. The following are the symbols/notations

p: Retailer price per unit
g: Greening cost per unit
w: Wholesale price per unit
c: Unit production cost
a: Elasticity of price, $a > 1$
b: Elasticity of greening cost, $0 < b < 1$
k: Demand scaling constant
μ: Overconfidence factor of greening, $\mu \geq 0$
$D(p, g)$: Demand function
$D^*(p, g)$: Demand with overconfidence factor
TP_C : Centralized profit ($)
TP_R : Retailer's profit ($)
TP_M: Manufacture's profit ($)
TP: Total Profit ($)
$TP_M{}^*$: Profit of the manufacturer with overconfidence factor
$TP_R{}^*$: Retailer's profit with overconfidence

Notations

Following is the notations

Assumptions

In the formation of the mathematical model, following assumptions are considered

- There is one manufacturer and one retailer in this supply chain model.
- Demand depends on price and the greenness of the product.
- No lead time and no shortages.

Mathematical Model Development

To analyze the sustainable supply chain with the effects of overconfidence, we use a game-theoretic modelling approach. In this supply chain modal, demand is influenced by both the retail price and the level of greening effort with a single manufacturer and a single retailer. Demand is represented by a Cobb–Douglas functional form: $D(p,g) = kp-agb$ (Ghoshel.al., 2024) (1) where g is the greening effort,p denotes the retail price, $k > 0$ captures the market potential, $b > 0$ represents the elasticity of demand with respect to greening, and $a > 0$ represents the price elasticity of demand. Within the sustainable supply chains framework, the upstream manufacturer may inaccurately assess its greening cost by overestimating it, thereby misjudging value and giving wrong results. The higher the value of μ, $\mu \geq 0$ the higher the overestimation degree of the manufacturer's efforts. Also, when $\mu = 0$,showing a fully rational and unbiased behavior.

$$D^{*}(p, g) = kp^{-a}((1 + \mu)g)^{b}$$

Methodology

We begin by developing a centralized benchmark model in which the manufacturer and retailer cooperate to maximize the total profit of the supply chain, jointly determining the retail price and greening level. We develop decentralized models under a Stackelberg framework, in which the retailer takes the role of leader by determining the retail price, while the manufacturer, as the follower, chooses the wholesale price and level of green investment. To capture behavioral distortions, we incorporate an overconfidence parameter μ, $\mu \geq 0$, representing the extent to which the manufacturer overestimates the effectiveness of its greening effort. Equilibrium solutions are derived through backward induction, yielding the optimal price, wholesale price, and greening effort under both rational and biased settings. Finally, we conduct sensitivity and comparative statics with respect to the key parameters a, b, c, μ allowing us to assess when overconfidence mitigates inefficiencies such as double marginalization.

Mathematical Formulation of Model

Centralized Modal

To develop a centralized benchmark model in which the manufacturer and retailer cooperate to maximize the total channel profit, jointly determining the retail price and greening level.

$$TP_C = (p - c - g)kp^{-a}g^b \quad (2)$$

$$\frac{\partial TP_C}{\partial p} = kp^{-a}g^b + (p - c - g)k(-a)p^{-a-1}g^b \quad (3)$$

$$\frac{\partial TP_C}{\partial g} = (-1)kp^{-a}g^b + (p - c - g)kbp^{-a}g^{b-1} \quad (4)$$

Putting $\frac{\partial TP_C}{\partial p} = 0$, $\frac{\partial TP_C}{\partial g} = 0$ to get optimal values from equation (3) and (4)

$$\frac{\partial TP_C}{\partial g} = -kp^{-a}g^b + (p - c - g)kbp^{-a}g^{b-1} = 0$$

$$\frac{\partial TP_C}{\partial p} = kp^{-a}g^b + (p - c - g)k(-a)p^{-a-1}g^b = 0$$

$p = \frac{a(c+g)}{a-1}$, $g = \frac{b(p-c)}{b+1}$ solving both to get the optimal value of p and g

$p^* = \frac{ac(A+b)}{(a-1)A}$, $g^* = \frac{bc}{A}$ where $A = a - b - 1$

Centralized profit with overconfidence Factor

This is a centralized model an overconfidence factor μ in greening in which the manufacturer and retailer cooperate to maximize the total channel profit, jointly determining the retail price and greening level.

$$TP_C{}^* = (p - c - g)kp^{-a}(1+\mu)^b g^b \quad (5)$$

As $(1+\mu)^b$ is a constant so it does not affect the optimal values so all the optimal values are same as above $p^* = \frac{ac(A+b)}{(a-1)A}$, $g^* = \frac{bc}{(a-b-1)}$

Decentralized Model

To construct decentralized models usin Stackelberg framework, where the retailer acts a leader by setting the retail price, and manufacturer, as the follower, decides the whol price and greening effort.

$$TP_R = (p - w)(kp^{-a}g^b) \quad ($$

$$TP_M = (w - c - g)kp^{-a}g^b \quad ($$

Differentiate equation (6) with respect to p

$$\frac{\partial TP_R}{\partial p} = kp^{-a}g^b + (p - w)k(-a)p^{-a-1}g^b \quad ($$

Putting $\frac{\partial TP_R}{\partial p}$ =0 so from equation (8)

$$\frac{\partial TP_R}{\partial p} = kp^{-a}g^b + (p - w)k(-a)p^{-a-1}g^b = ($$

$$p^* = \frac{aw}{(a-1)} \quad (9)$$

Putting the value of p in equation (7)

$$TP_M = (w - c - g)k\left(\frac{aw}{(a-1)}\right)^{-a}g^b \quad (10)$$

Now differentiate equation (10) w.r.t. g and w

$$\frac{\partial TP_M}{\partial g} = k\left(\frac{aw}{(a-1)}\right)^{-a}[-g^b + (w - c - g)bg^{b-1}$$
(11)

$$\frac{\partial TP_M}{\partial w} = kg^b \left(\frac{a}{(a-1)}\right)^{-a}[(w - c - g)(-a)w^{-a-1} + w^{-a}] \quad (12)$$

Putting $\frac{\partial TP_M}{\partial g} = 0$, $\frac{\partial TP_M}{\partial w} = 0$ so from equations and (12)

$$g^{b-1}k\left(\frac{aw}{(a-1)}\right)^{-a}[-g + (w - c - g)b] = 0$$

$$w^{-a-1}kg^b \left(\frac{a}{(a-1)}\right)^{-a}[-a(w - c - g) + w] =$$

Implies that $g = \frac{(w-c)b}{(1+b)}$, $w = \frac{a(c+g)}{(a-1)}$

$g = \frac{(w-c)b}{(1+b)}$, $w = \frac{a(c+g)}{(a-1)}$ on solving both to g optimal values of g and w

$w^* = \frac{ac}{(a-b-1)}$, $g^* = \frac{cb}{(a-b-1)}$

Now putting the values of w^* and g^* in equatio

$p^* = \frac{aw}{(a-1)} = \frac{a}{(a-1)}\left[\frac{ac}{(a-b-1)}\right]$

Decentralized Model with Overconfidence

To capture behavioral distortions, we incorporate an overconfidence parameter μ, representing the extent to which the manufacturer overestimates the effectiveness of its greening effort. Where the retailer acts as the leader by setting the retail price, and the manufacturer, as the follower, decides the wholesale price and greening effort using the Stackelberg framework in this decentralized modal.

$$D^{*}(p, g) = kp^{-a}((1 + \mu)g)^{b} \quad (13)$$

$$TP_{R}{}^{*} = (p - w)(kp^{-a}((1 + \mu)g)^{b} \quad (14)$$

$$TP_{M}{}^{*} = (w - c - g)kp^{-a}((1 + \mu)g)^{b} \quad (15)$$

As $(1 + \mu)^{b}$ is a constant so it does not affect the optimal values so all the optimal values are same as above$g^{*} = \frac{cb}{(a-b-1)}$,$w^{*} = \frac{ac}{(a-b-1)}, p^{*} = \frac{a}{(a-1)}[\frac{ac}{(a-b-1)}]$

Numerical Validation And Concavity

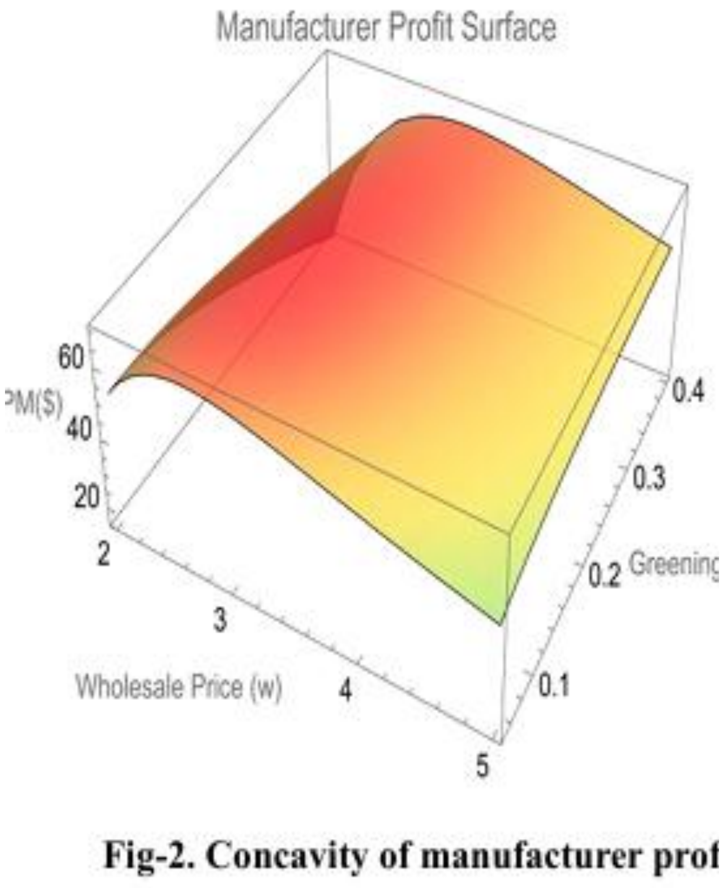


Fig-2. Concavity of manufacturer prof

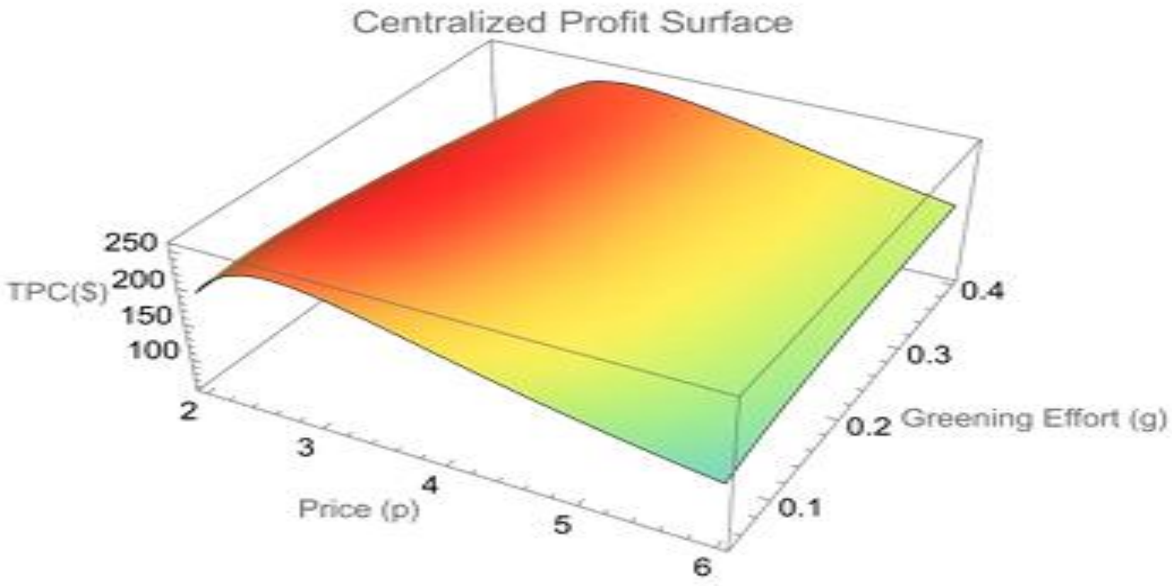


Fig-3. Concavity of centralized profit

Concavity

Figure 2 presents the manufacturer's profit TPM (w, g) surface as a function of wholesale price w and greening effort g, while figure 3 illustrates the centralized profit TPC (p, g) surface in terms of retail price p and greening effort g. In both cases, the surfaces exhibit a clear concave shape with a single peak, confirming that profit functions are strictly concave. This means that there exists a unique optimal combination of decision variables that maximizes profit. The curvature of the plot forms a dome-like shape, which also indicates concavity. The profit reaches its highest value near this point. Overall, both graphs visually confirm the concavity of the respective profit functions with respect to the decision variables.

Numerical Comparison

Validation of model by taking the values from previous literatures and some values taken hypothetically for optimal values and profit functions: $a = 2.4$, $b = 0.15$, $c = 1.5$, $k = 3500$, $\mu = 0.4$. (Ghosh et al., 2024)

Table 2. Optimal values and profit values

Variables	Centralized model	Centralized model with overconfidence	Decentralized model	Decentralized modal with overconfidence
p	2.88	2.88	4.93	4.93
g	0.18	0.18	0.18	0.18
w			2.88	2.88
D	213.70	224.76	58.82	61.86
$TP_M(\$)$			65.87	69.28
$TP_R(\$)$			125.28	131.77
$TP_C(\$)$	256.44	269.72		
$TP(\$)$			191.16	201.06

Sensitivity Analysis

Following are the graphs of the sensitivity analysis.

Fig-4. Profit with respect to a

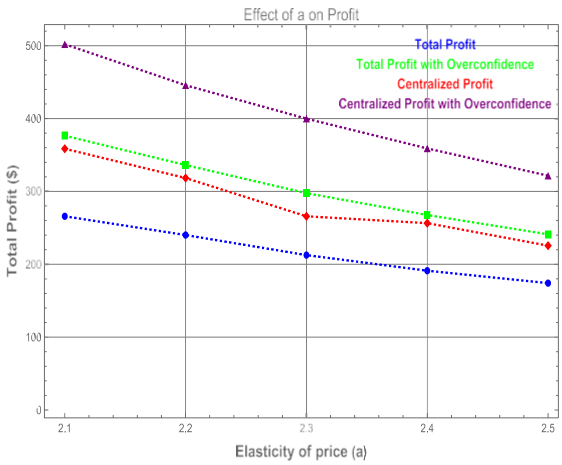


Fig-5. Fig-4. Profit with respect to b

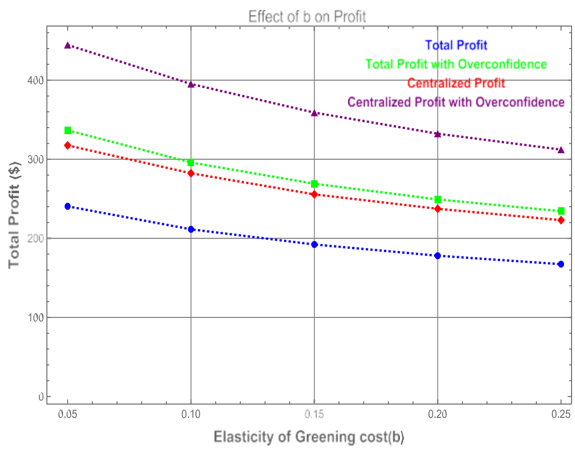


Fig-6. Fig-4. Profit with respect to c

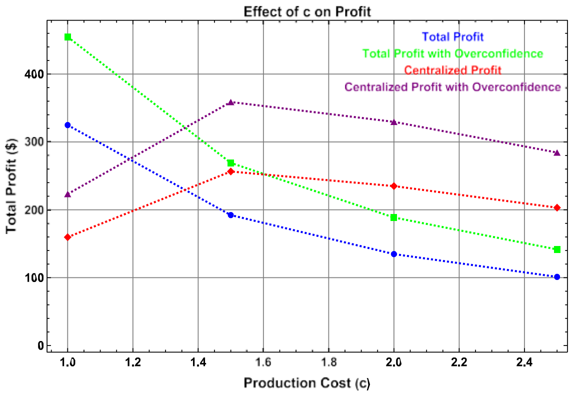


Fig-7. Fig-4. Profit with respect to μ

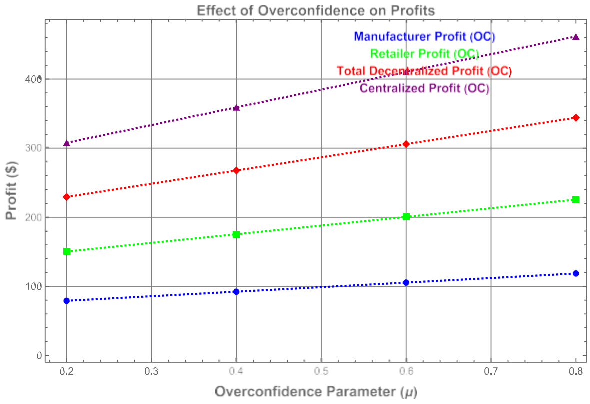


Figure 4 shows that as the elasticity of price , a increases, all profit values decline steadily. This is expected, as a higher a implies greater price sensitivity — meaning the demand drops more sharply with price. Overconfidence significantly improves both total and centralized profits, but the relative decline across all curves suggests that price sensitivity strongly influences profitability regardless of coordination strategy.

Figure 5 shows that as the elasticity of greening cost, b increases, profits decrease across all scenarios. This is because higher b makes sustainability investment less cost-effective, thereby reducing net gains. Overconfidence still leads to noticeably higher profits, especially in centralized settings. The pattern indicates that systems are vulnerable to increasing greening costs unless behavior-driven optimism is leveraged.

Figure 6 reveals a sharper decline in profits with increasing c, particularly for total profit under the standard model. Interestingly, centralized profit with overconfidence maintains a relatively stable trend,

highlighting its resilience. The benefit of overconfidence becomes more pronounced at higher production costs, suggesting it can act as a buffer against cost-induced performance drops.

Figure 7 shows that all profit measures increase with the overconfidence parameter , μ Manufacturer profit rises steadily but at a slower rate, while retailer profit grows more sharply, reflecting the retailer's stronger benefit from overconfidence. As a result, total decentralized profit increases almost linearly, demonstrating that overconfidence can actually enhance overall supply chain performance. Centralized profit exhibits the steepest growth, indicating that coordination amplifies the positive effects of overconfidence. Overall, the results reveal that higher μ improves profits across all cases, with the greatest gains achieved under centralized decision-making.

CONCLUSION AND FUTURE SCOPE

This study examined how manufacturer overconfidence shapes decision-making and performance in green supply chains under centralized and decentralized structures. The findings provide clear answers to the research questions and highlight several key insights.

First, centralized coordination offers superior alignment between economic and environmental objectives. However, the presence of overconfidence changes this dynamic. Even though the optimal decision variables—such as retail price, wholesale price, or greening effort—remain unchanged, overconfidence increases the perceived effectiveness of greening, which in turn raises demand and profitability. This effect occurs in both coordination structures but is more pronounced in centralized systems due to stronger joint decision-making.

Second, the results indicate that overconfidence, though typically seen as a behavioral bias, can partially offset inefficiencies in decentralized supply chains. While it does not completely resolve coordination problems, it improves financial outcomes for both the manufacturer and the retailer, thereby narrowing the gap between decentralized and centralized performance.

Finally, under the Cobb–Douglas demand framework, overconfidence does not alter the form of the optimal solutions but magnifies their outcomes. The manufacturer's inflated expectations of greening returns lead to stronger market responses, translating into higher realized profits and greater consumer adoption.

Overall, this study provides a counterintuitive insight: psychological biases such as overconfidence, rather than always harming performance, may under certain conditions strengthen both environmental sustainability and business profitability.

From the managerial point of view this study highlights that behavioral traits, such as manufacturer overconfidence, can unexpectedly enhance both sustainability and profitability in supply chains that integrated contracts and joint decision frameworks not only resolve pricing and investment inefficiencies but also amplify the positive effects of behavioral tendencies, enabling companies to align environmental goals with business growth.

Thus, overconfidence encourages stronger greening efforts, which raise consumer demand and improve financial outcomes, even when decision variables like price or investment appear unchanged.

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