Implementing The United Nations Sustainable Development Goals to Supply Chains with Behavioral Consumers

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Abstract

We identify that the United Nations (UN) Sustainable Development Goals (SDGs) of 7, 9, 12 pertaining to industry investment, innovation, affordability, clean product, and responsible consumption/production are relevant for the firms operating in closed-loop supply chain (CLSC) structures. We show how these goals can be implemented into a CLSC in which downstream manufacturer serves different types of consumers and engages in vertical relations with a supplier in the upstream. While the supplier invests in a green component, the manufacturer produces the final green product. The manufacturer diversifies its customer base and meet their demands through contracts and a variety of pricing options. Specifically, at the end of the supply chain there are three different customer groups: "contract customers", "green-conscious customers", and "wholesale market customers". While the firms execute sustainability Goals of 7 and 9, the behavioral consumers who are the contract and green-conscious customers are altruistic, consume responsibly, and hence fulfill the Goal 12. We show that green consciousness and altruism play an important role on firm profitability and production. Furthermore, the SDGs proposed by the UN have welfare-improving implications. In particular, when the SDGs are implemented, all parties (firms and consumers) are better off compared to the benchmark case under which no SDGs are applied.

Key words: Sustainability; Closed-loop supply chain; Endogenous return; Process innovation; Green-Consciousness; Responsible consumption; Contracts. JEL codes: D02;D64;D91;L11

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1 Introduction

In September 2015, the General Assembly of the United Nations (UN.org, 2015) announced "The 2030 Agenda for Sustainable Development" emphasizing 17 sustainability goals. These Sustainable Development Goals (SDGs), or sustainability goals in short, aim to prosper nations through the following objectives, which are in order: "no poverty" (Goal 1), "zero hunger" (Goal 2), "good health and well-being" (Goal 3), "quality education", "gender equality", "clean water and sanitation", "affordable and clean energy" (Goal 7), "decent work and economic growth", "industry, innovation and infrastructure" (Goal 9), "reduced inequalities", "sustainable cities and communities", "responsible consumption and production" (Goal 12), "climate action", "life below water", "life on land", "peace, justice and strong institutions", "partnerships for the goals" (Goal 17). These sustainability goals have been unanimously adopted by 193 Heads of State at the UN summit and shared the common vision of improving the well-being of nations and tackling climate change over the next 15 years (UN.org).

This paper focuses on the SDGs and identifies that a subset of them are highly relevant and can be implemented by business firms operating in supply chains. Specifically, we consider the Goal 7, targeting "affordable and clean energy", the Goal 9, aiming "industry, innovation and infrastructure", and the Goal 12, proposing "responsible consumption and production". We show how these goals can be adopted to a behavioral sustainable supply chain management framework. Specifically, we show how these goals affect supply chain conduct and improve the performance of a closed-loop supply chain (CLSC) in the presence of behavioral consumers.

We contribute to the literature by showing how to implement the relevant UN SDGs into CLSC settings. We in particular relate the SDGs to lean practices leading to responsiveness, sustainability, process innovation, waste reduction, and performance. We find that implementation of the SDGs results in higher profits for the firms, better products and prices for the consumers, and cleaner environment for the society facilitated by responsible consumption and waste reduction. This implies that the UN SDGs are not only feasible and practical, but also sustainable and profitable. In fact, this result is parallel to the objective of triple-bottom line pillars of sustainability in the context of supply chains (Rajeev et al., 2017).

In the proposed CLSC framework (see Figure 1), a supplier of the intermediate product invests in a green product/component which will be used by the downstream manufacturer (M) to produce a green product. Some of the end-users are environmentally conscious and buy green/clean product only.

Some consumers are altruistic and responsible in the sense that they are willing to give up some of their consumption units and return them to the manufacturer who sell them to other customers who value the product the most. While facing the green-conscious consumers", the manufacturer (M) meets demands of all consumer types and competes with other manufacturers (who could be "clean" or "dirty") in the wholesale market. Specifically, at the end of the supply chain there are three different consumer types ($T1$, $T2$, $T3$) who buy the product from M. Specifically, $T1$ and $T2$ consumers are behavioral and $T3$ consumers are rational. The first type of consumers is subject to a contract that dictates the terms of agreement on price and return quantity. We coin this type as "contract customers", in short $T1$. The second type of consumers called "green-conscious customers" or simply "green customers", denoted by $T2$, is responsive to both price and product greenness level, and faces a single firm only, the manufacturer M. Some of consumption units of $T2$ customers, who responsibly consume, could also be curtailed by M per terms dictated in the contract. The third type of consumers participate into the wholesale market in which they can buy the product from several producers including the manufacturer M. We name them as "wholesale market customers", denoted by $T3$. The contract and green customers can return some portions of their purchases based on the terms of contracts and the monetary incentives given to them. These returns can be in form of curtailing the output and then selling it to the market customers when the wholesale market conditions are favorable for the manufacturer.

In the CLSC, firms and consumers engage into the SDGs which will impact production, environmental quality, investments, returns, prices, and profits. Specifically, the supplier who produces the intermediate product engages in Goal 9 aimed at investing and producing environment-friendly "green component" which will also provide benefits to the environment. The manufacturer in the downstream executes Goal 7 and produce and sell the final green product to three types of consumers at different prices. Essentially, the manufacturer executes price discrimination over consumer types. The manufacturer sets the terms of the contracts, chooses the outputs over consumer types, manages the returns and sells the final product across markets. All firms strive to maximize their expected profits. We characterize Stackelberg equilibrium outputs, investments, and prices to quantify the impact of the UN SDGs on the CLSC performance in the presence of behavioral consumers.

The novelties of this paper are the following. First, we show that the SDGs 7, 9, and 12 are relevant and can be incorporated into a behavioral supply chain framework. We interlink the goals with lean practices, and then reveal that these SDGs can increase the performance of the chain (higher profits for the firms, superior/green product for the consumers). Second, we offer heterogeneous customer types respecting the realm of green and non-green consumers, incorporating market and non-market consumers depending on their size and preferences, and considering consumers with social responsibility and altruism. Third, different than the classical treatment of product returns in CLSC literature in which used, end-of-life, or defective products have been collected, recycled and utilized in making new products, we give an extended definition of product returns (reverse logistics) by realizing that the manufacturer could curtail or cut-back or recall the outputs from some consumers and then sell them to others whenever market conditions are favorable. With this new treatment, manufacturer will be able to save virgin material and divert outputs to consumers who demand it the most. Consumers who agree with curtailment will be rewarded which is a treatment akin to a payment for return (such as rebate). Some consumers could return the used-product for environmental reasons so that they would be recycled instead of ending up in landfill. Parallel to this concept, in the new scheme some consumers agree to consume less as they are environmentally conscious, altruistic and sacrifice from (over)consumption which will be diverted to other consumers, and hence waste generated in new production could be avoided. Consequently, in this CLSC the returns are atypical such that the manufacturer has the right to curtail or withhold some of the units from the sale in exchange for a monetary incentive as determined in the contract. We show that this kind of return behavior facilitates higher profits for the firms, higher savings for the consumers, and lower waste. Fourth, all parties in the CLSC engage in sustainability programs. The supplier invests in a green component, the manufacturer produces a green product, and the consumers (of $T1$ and $T2$ types) responsibly consume the green product by accepting curtailment in their demands which provides benefits to all consumer types.

We find that **a)** if all goals (Goals 9, 7, and 12) are applied, then CLSC firms and consumers are better off compared to the case under which no SDGs are applied. Furthermore, applying all goals is a Pareto-dominant strategy; **b)** behavioral consumers are the key to enhance performance of supply chain. Furthermore, the manufacturer exercises price discrimination (through contract price to $T1$, monopoly price to $T2$ and competitive price to $T3$) which is another form of profit-enhancing strategy. In addition, serving to $T1$ and $T2$ customers facilitates hedging against uncertainty faced in $T3$ market. This also provides benefits to M as well as S and maintains a certain cash flow in $T1$ and $T2$ markets where there is no uncertainty. This implies that contracts in markets $T1$ and $T2$ help reduce risks in $T3$ market; **c)** the Goal 9 involving investment and industry innovation is the most important SDG to increase the profitability of CLSC. The Goal 9 helps achieve other goals of affordable and clean product (Goal 7) and responsible consumption/production (Goal 12); **d)** The existence of green-conscious customers ($T2$ type) urges S to invest in green component. This will result in completion and sale of green product in the downstream. As green-conscious customers value green attributes of product, both S and M will produce more, charge higher prices and increase their profits. While green consumers pay a high price, they benefit from consuming a "superior/green product"; **e)** The returns/curtailments improve profits significantly. Whenever the price in $T3$ market is high enough, M will be able to withhold some sales from $T1$ and $T2$ consumers and sell them to $T3$ where it is most demanded. This strategy also improves the welfare of $T1$ and $T2$ customers.

The paper is organized as follows. Section 2 connects the paper to the literature. Section 3 introduces the CLSC model and assumptions. Section 4 presents the Stackelberg equilibria in the decentralized CLSC. Section 5 quantifies the benefits of SDGs. Section 6 studies cases in which the SDGs are partially implemented and Section 7 concludes with future research directions.

2 Connections with Literature

Behavioral studies are concerned with human behavior which deviates from rational decision making springing from optimization and strategic considerations. Operations and supply chain management research in conjunction with behavioral studies deal with cognitive biases, personal and social preferences, and cultural norms (Loch and Wu, 2007). This type of behavior impacts product design, management, and operations (Gino and Pisano, 2008).

A recent paper (Genc and De Giovanni, 2021) considers behavioral issues in a new dynamic model in which a manufacturer makes pricing and green investment decisions, and meets different demand segments of emotional, conscious, and rational consumers. They distinguish emotional consumers from conscious consumers in that the former base purchasing decisions on firm's contribution to the environment, while the latter consider both product price and the impact of firm's product on the environment. Emotions are stochastic, dynamic, and accumulate over time. Consciousness is instantaneous and memoryless. Emotions are part of extended consciousness and amalgamate old experiences with new ones, but consciousness is instantly derived from a sequence of attention, perception, and action. While emotional consumers take into account of firm's current and past green initiatives, conscious consumers only react to the current actions of the firm. They find that emotional consumers have the largest impact on firm investments. Further, whether the firm has environmental targets or restrictions, all demand segments should be satisfied regardless of their impact on firm profits. However, the current paper, different than others, introduces green consciousness and altruistic consumer behavior for a new green product development in a CLSC pursuing the goals of the UN SDGs.

This paper is also linked to “lean manufacturing” in supply chain literature. We interpret the UN Sustainability Goals of 7, 9, and 12 as lean activities aiming at process innovation, affordability, sustainability, responsiveness, and waste reduction. While the research has shown the interlinks between lean practices and supply chain management (Martinez-Jurado and Moyano-Fuentes, 2013), the literature has overlooked the relationships between lean practices within the CLSC settings (Genc and De Giovanni, 2020). A CLSC may be viewed as vertical relations in multi-level markets involving both forward flows of raw materials, intermediate and final products, and backward flows of used products (Guide and Van Wassenhove, 2009). The backward activities are carried out to enhance both sustainability and economic performance through reverse logistics management. In general, the CLSCs adjust their production process to accommodate both used products (through returns/take-backs) and virgin materials simultaneously (De Giovanni et al., 2016). However, managing returns can be expensive and time consuming as firms need to deal with uncertainty linked to time, quantity and quality of returns (Fleischmann et al., 1997). The CLSC models have investigated several issues to incentivize returns such as promotional programs (Savaskan et al., 2004), monetary incentives (Kaya, 2010), and trade-in policy (Genc and De Giovanni, 2017). Govindan et al. (2015) review the recent literature and propose future research directions for CLSCs. The lean manufacturing is an integrated manufacturing system optimizing the production resource utilization and reducing the waste (Chavez et al. 2015). Lean manufacturing covers all stages of product, from product conceptualization to its distribution (Jasti and Kodali, 2015) using various techniques (Yang et al., 2011). The discussion of the triple-bottom line has led the attention to lean manufacturing because lean programs aim at higher market performance (Gimenez and Sierra, 2012) and operational targets (Rajeev et al., 2017). The literature has also adopted lean programs to achieve environmental targets via implementing green manufacturing practices and environmental design (Gotschol et al., 2014). Accordingly, firms can mitigate the negative effects of their operations on the environment. This environmental objective is surely parallel to the UN SDG 7. In fact, lean manufacturing can be environment-friendly and present value not only to environmental sustainability but also to economic and social sustainability (Fliedner and Majeske, 2010).

Furthermore, the lean manufacturing is commonly regarded as “corporate lean programs” because they aim to improve sales, operational benefits and environmental performance. Genc and De Giovanni (2020) call this type of lean activity as “strategic lean” and show how innovation-led lean programs improve the performance of CLSCs. On the other hand, some innovation-led lean programs would only target process innovation which has the goal of production cost reduction. The literature has often referred to this type of lean as “internal lean programs”. For example, Chavez et al. (2015) show that internal lean programs have a positive effect on both operational and organizational performance. Genc and De Giovanni (2020) show that strategic lean programs are more effective than process innovation lean programs as the former contributes more to the supply chain performance.

Within the framework of CLSCs, the UN SDGs can be adopted as lean practices. On one hand, they can contribute to "responsible consumption (Goal 12)" by withholding sales from some customers (equivalently, curtailing the consumption quantity) and selling it to the other consumers who demand it. This in turn may result in waste reduction, virgin material saving, and hence provide an improvement for the environment. The Goal 12 therefore is in the spirit of a backward activity in CLSC frameworks, facilitating better usage of "returned product", instead of producing new product from virgin material, and therefore providing incentives to consumers and firms to increase the efficiency in the value chain. On the other hand, the Goal 7 is parallel to the adoption of lean practices that can be more operationally oriented and focused on process innovation to make the process greener. The literature has treated these two goals separately. First, production process can be improved by achieving efficiency in work and using available materials effectively. These lean practices can result in environmental efficiency (Rothenberg et al., 2001) through waste reduction. Further, the implementation of process innovation practices can decrease production cost (Kobayashi, 2015; Genc and De Giovanni 2020) via investment. We cover this aspect of lean manufacturing by adopting the Goal 9. Second, firms can invest in pollution prevention programs as part of lean activity, which can be achieved by changing the structure of production process (Rothenberg et al., 2001). In this paper, we model the returns (i.e., demand curtailment or supply withholding)-which is a proxy to environmental performance- as a function of a lean practice which measures greenness level of investment (Goals 9 and 7). In particular, the lean practices that target green production and clean products will urge consumers to buy and keep them as long as possible. Indeed, this is in the realm of consumption behavior in this century: consumers have inclined towards green products and been sensitive to environmental consequences of their purchases. Firms may exploit this consumption behavior by incorporating new green concepts into their businesses and increase their sales and profits (Laroche et al., 2001).

3 Model

We consider a tractable two-echelon CLSC structure involving behavioral consumers.[1] In the upstream there is a supplier (S) (e.g., a component maker) who produces a homogeneous intermediate product. In the downstream there is a manufacturer (M) who buys the intermediate product from the supplier, produces and sells a final product. At the end of the supply chain there are three different consumer types ($T1$, $T2$, $T3$) who buy the final product. The first type of consumers is subject to a contract that dictates the terms of agreement on price and return (i.e., curtailment) quantity. They are called "contract customers", in short $T1$. The second type of consumers is called "green-conscious customers", denoted by $T2$. They form their green consciousness based on supplier's green investments, and are price responsive. They buy the green product from the manufacturer M who is the sole producer of the green product. The third type of consumers participate into a wholesale market in which there are many producers including the manufacturer M. We coin these consumers as "wholesale market customers" or in short "market customers", denoted by $T3$. The contract and green customers can return (or accept curtailment of) some portions of their purchases based on the terms of contracts and the monetary incentives they are offered. These returns will be taken back by M and sold to the market customers when the wholesale market conditions are favorable to the manufacturer. Whether the final product is perishable or durable, the returns or cut-backs may come in the form of withholding output or immediate reductions in deliveries (in case of perishables) or getting back the sold product (in case of durable goods) whose terms are determined in the contracts signed between M and consumers ($T1$, $T2$).

An example for such a CLSC is that S produces photo-voltaic cell or wind turbine/generator, and M produces electricity. $T1$ consumers refer to rural customers of electricity who have flexibility in their consumption and could use their own generators from time to time instead of buying electric power from its supplier. $T2$ consumers are green-conscious residential electricity consumers who consume wind or solar energy only. $T3$ consumers refer to industrial and/or business customers who are not concerned

[1]While two-tier supply chains have been commonly examined, the performance assessments of supply chains with more than three connected tiers are rare (Wilhelm et al. 2016). In order to deal with effective management of sustainability issues, Sauer and Seuring (2019) perform a Delphi study (a structured group communication) and propose a cascaded multi-tier sustainable supply chain (MT-SSCM) approach linking the upstream and the downstream in minerals supply chain.

with generation source of electricity, whether it is renewable or non-renewable.

In this supply chain, firms as well as consumers engage in the SDGs which will impact the outcomes (productions, investments, returns, prices, and profits) as we show in Sections 4-6. Specifically, while the upstream supplier (S) produces the intermediate product it also engages in Goal 9 (the industry innovation achieved through green investment) aimed at producing environment-friendly "green component/part" which will provide benefits to the environment and all supply chain members. The downstream manufacturer's (M) role is to execute Goal 7 (affordable clean product) and produce and sell the final product to the three consumer types at different prices and quantities. While the manufacturer price-discriminates over consumer types, its objective is to set the terms of contracts, choose production quantities, manage returns/curtailments. The CLSC framework implementing the SDGs is depicted in Figure 1.

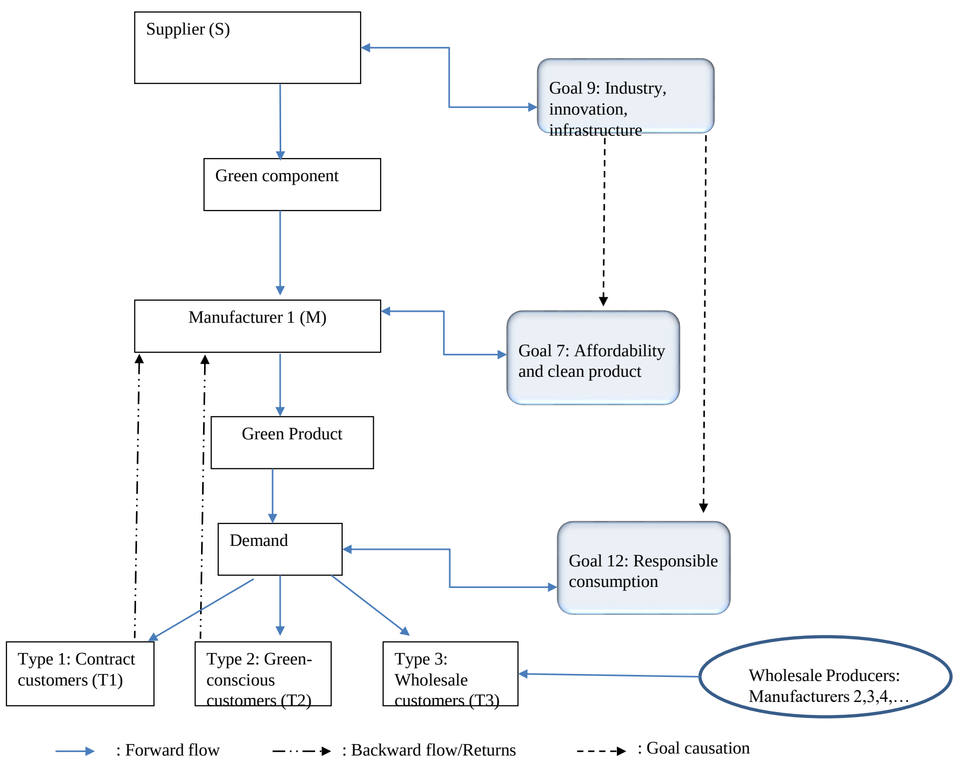

Figure 1: The CLSC Structure with the UN Sustainability Goals of 7,9,12

The types of consumers ($T1, T2, T3$) of the final product vary in terms of their preferences for product specificity and risk attitude. $T1$ type consumers are risk-averse, and therefore they purchase their demand quantity at the negotiated contract price. However, they have some flexibility for their own consumption and therefore their demand may be curtailed by M in exchange of a reward. In the contract, M and $T1$ agree on the rate of curtailment, product price, and rebate per return/curtailment. The curtailment rate is exogenous as we focus on the impact of SDGs on supply chain operations rather than designing an optimal contract. Nevertheless, M will optimally choose quantity supplied to the contract customers. $T2$ type consumers are price responsive and buy from M only. The reason why they buy from M only is that $T2$ consumers are behavioral and sensitive to the environmental impact of the product. Also, similar to $T1$ customers, $T2$ customers participate into the sustainability goal (Goal 12, the responsible consumption) which gives M a right to curtail the demand of $T2$ customers, whenever M recalls it. The contract between M and $T2$ determines the rate of curtailment and the reward for each unit of reduction in demand. Consumer participation in the sustainability programs can reduce waste and provide financial benefits to all parties. In fact, $T2$ consumers can reduce their consumption without increasing its product price and also earn a rebate for each unit of consumption reduction. M could sell this extra quantity in the wholesale market and earn a higher profit than it could earn from $T2$ consumers. Finally, the other consumer type, denoted by $T3$, can access to the wholesale market in which there are many buyers and sellers. $T3$ customers are subject to wholesale market price and M is just a competitive fringe.

The formal model exposition with notation is as follows.

$T1$ contract customers' demand for the final product is q_1 at a price of p_1. M can recall or curtail αq_1 amount, where $0 \leq \alpha < 1$, at a rebate ϵ_1 per unit. Therefore, the actual consumption of $T1$ customers is

$$d_1 = \begin{cases} q_1 & if \;\; r_1 = 0 \\ (1-\alpha)q_1 & if \;\; r_1 > 0 \end{cases} \tag{1}$$

where demand curtailment for contract customers is

$$r_1 = \begin{cases} 0 & if \;\; p_3 \leq p_1 + \epsilon_1 \\ \alpha q_1 & if \;\; p_3 > p_1 + \epsilon_1 \end{cases} \tag{2}$$

M withholds αq_1 whenever expected or realized wholesale market price p_3 paid by $T3$ customers is higher than the contract price p_1 plus the monetary incentive or rebate, $\epsilon_1 > 0$, paid to $T1$ per curtailed quantity. That is, M curtails and diverts sales to market customers if the $T3$ market conditions are favorable. In the contract between M and $T1$, the values (ϵ_1, p_1, α) are negotiated and exogenously settled, as this is common for some contracts. However, M endogenously chooses the quantity to be sold to $T1$ based on cost of production and sales to other consumer types.

$T2$ green customers' demand is both green-conscious and price responsive. Specifically, their inverse demand is

$$p_2(q_2) = a_2 - b_2q_2 + c_2G \tag{3}$$

in which the parameters a_2, b_2 are positive. G refers to the level of green consciousness of $T2$ consumers or the "greenness level" of the product, defined below in (4) as a function of green investment, carried out by the upstream supplier (S). When the supplier invests in green product development (parts and components) and consumers base their purchasing decisions on it, the demand for final product will shift. The parameter c_2 could be positive or negative. When it is positive demand shifts up, when it is negative demand shifts down. How much it shifts also depends on the magnitude of green investment. Because $T2$ customers demand green product and the supplier invests to produce it, p_2 changes in the greenness level (or environmental performance) G. Specifically, the green investment has a positive environmental implication expressed by

$$G(I) = eI \tag{4}$$

where $e > 0$ reflects the marginal environmental benefit from each unit of green investment (I). However, how $T2$ customers interpret the environmental implication of the product is scaled by the parameter c_2. If it is positive, consumers welcome the supplier's green investments. If it is negative, consumers feel dissatisfied by the green product development.

The green customers also engage in sustainability program represented by Goal 12 which grants M right to curtail their demand, per terms dictated in the contract. Specifically, the amount of returns or cutbacks from $T2$ customers is

$$r_2(I) = \theta - \gamma I \tag{5}$$

The green consumers return less when the greenness level of product increases. That is, the higher the greenness level of product the lower the returns are. This is because their utility rises up in green product consumption. The returns do not exceed quantity demanded, and therefore the relation $a_2 > b_2\theta$

should hold. Further, $\theta > \gamma I$ must hold to have a positive return. Whenever the return or curtailment occurs, M can sell quantity r_2 to the market customers ($T3$) at price p_3. Note that the return function (5) is endogenous and is a function of green and lean investment. This assumption follows from a trend in the CLSC literature that the returns should be a function of firm strategy (Kaya (2010), Esenduram et al. (2016), Hong et al. (2017), Genc and De Giovanni (2017, 2020)). A notable feature of return behavior of green customers in (5) is that when the greenness level of product goes up there will be less returns which refers to lower profits for M in $T3$ market. In summary, $T2$ customers can enjoy not only a green product but also a lower average price. Finally, the wholesale customers and producers are in the $T3$ market. The wholesale price $\widetilde{p_3}$ is stochastic. Specifically, the inverse demand in $T3$ market is

$$\widetilde{p_3}(Q) = a_3 - \widetilde{b_3}Q \tag{6}$$

where Q is the total demand quantity in the wholesale market. The coefficients a_3 and $\widetilde{b_3}$ are all positive and represent the maximum price and a stochastic price response rate, respectively. The market customers do not engage in sustainability program. They have no returns nor are they concerned with product greenness. The manufacturer will decide how much to sell in the wholesale market. Let this quantity be q_3, then total demand quantity in the wholesale market is $Q = q_3 + Q_{-3}$, which is M's quantity supplied q_3 plus other manufacturers' total production Q_{-3}.

Note that because M is a small competitive firm in the wholesale market, it can supply any quantity (upto its capacity) at the competitive price $\widetilde{p_3}$.

The manufacturer M maximizes its profit to choose quantities to be sold across customer groups: the quantity q_1 to $T1$ customers, the quantity q_2 to $T2$ customers and the quantity q_3 to $T3$ customers. M will charge contract price to contract customers, monopoly price to green customers and competitive price to market customers. Let the total output of M be $q = q_1 + q_2 + q_3$.

While M serves to three different demand groups, it also engages in sustainability program through managing returns. M can guarantee a certain cash flow in $T1$ market and hedge itself against price fluctuations in $T3$ market. In $T2$ market, M enjoys selling to green customers as it exploits their green consciousness by charging a monopoly price. The wholesale market customers ($T3$) are served once the demands of contract customers and green customers are fulfilled. Therefore, M can always sell remaining production to the wholesale market.

The long-run total cost of final good production is quadratic and separable in the cost of intermediate good (the first term) and the cost of manufacturing the final good (the second term):

$$C(q_1, q_2, q_3) = w(q_1 + q_2 + q_3) + (c_M - d_I)(q_1^2 + q_2^2 + q_3^2), \tag{7}$$

where $c_M - d_I > 0$ must hold so that cost of manufacturing is positive. While an alternative cost function could be embedded into the model, increasing marginal costs are common in industries including power generation, oil and gas, metals and minerals. Further, separable cost assumption simplifies analysis and renders tractable solutions. From operational point of view, the separable costs function may be viewed as independence of plants/sites used to serve customers. This assumption could be relaxed to suit to some specific industries if the costs were to be dependent.

When $d_I > 0$ holds, the marginal production cost goes down, caused by upstream supplier's investment on green component. For example, this cost reduction might come from a new design of a green part which would cause a cost reduction in making the final product. The first term of total cost function reflects the spending on intermediate product, which is the main input for producing the final good, given that one unit of input is used to make one unit of output.[2]

The objective function of M is to maximize its expected profit function:

$$\max_{q_1, q_2, q_3} E\Pi^M = \underbrace{q_1 p_1 + q_2 p_2(q_2, I) + q_3 \widetilde{p_3}(Q) - C(q_1, q_2, q_3)}_{\text{Forward profit}} + \underbrace{(r_1(q_1) + r_2(I))(\widetilde{p_3} - p_1 - \epsilon_1)}_{\text{Backward profit}} \tag{8}$$

This profit function is stochastic as the price $\widetilde{p_3}(Q)$ in the wholesale market is uncertain.

In the backward profit expression, the returns/curtailments over customer types are valued the same. The marginal benefit of returns from $T1$ customers is equal to the marginal benefit of returns from $T2$ customers. This is because the returns will be sold at the same price to $T3$ customers, and the marginal costs of producing and serving to $T1$ and $T2$ customers are the same.

The supplier (S) in the upstream layer of industry produces an intermediate product (e.g., green engine, car battery, wind generator blades, photo-voltaic cells) and engages in process innovation (resulting in less emissions for the fossil fuel-burnt engines, or producing high capacity long-lasting battery,

[2]On the other hand, it could happen that the cost of production would go up, even if the investment is positive. An example for this case is that supplier engages in battery development for electric cars produced by downstream manufacturer. In that case, $d_I < 0$ might hold. Therefore, depending on the industry d_I could take a positive or a negative value in the model setting. If $d_I > 0$ then it is called "positive process innovation". If $d_I < 0$ then it is called "negative process innovation".

or designing efficient blades for wind turbines, or developing new photo-voltaic cells to store more solar energy). We assume that there is one-to-one relationship between intermediate and final products. That is, one unit of intermediate product is used to make one unit of final product so that quantity demanded for final product is equal to quantity demanded for intermediate product. For example, one car battery is needed per car; or one set of wind blade is used to make one wind generator. Otherwise, one could easily rescale M's output q.

The green and lean investment cost function of S is quadratic:

$$D(I) = h_1 I^2/2 \tag{9}$$

where $h_1 > 0$ so that the marginal cost is increasing in the investment I. One could add a fixed cost into Eq. (9), but this will not affect the optimal green investment decisions. However, a fixed cost would clearly impact the profitability. While it is costly for S to invest, green investment and innovation are intended to boost demand for its green product (Genc, 2017).

The cost of producing intermediate product is also affected by the industry green investment and innovation. The cost of producing intermediate product is linear:

$$F(q_S) = (f_S - f_I)q_S, \tag{10}$$

where $f_S > 0$ is the marginal cost of production without industry innovation and $f_S - f_I > 0$ is the marginal cost with industry innovation. If $f_I > 0$ holds, then the marginal cost of production goes down, implying industry innovation leading to positive process innovation (e.g., a new efficient design of wind turbine blades or of photo-voltaic cells)[3]

The green investment carried out by the supplier can provide benefits to all stakeholders. The role of green investment is that *i*) it can entail process innovation, hence causing cost reductions; *ii*) it directly impacts the demand of green-conscious customers and indirectly impacts demand of market and contract customers. Therefore, it affects sales and profits; *iii*) it has a positive impact on the environment by facilitating more green production (cost reduction effect reflected by the second term in M's cost function in (7)) and therefore entails less pollution overall.

The objective of S is to maximize its expected profit function to choose its wholesale price w and

[3]We assume that process innovation may reduce the marginal cost of production so that $f_I \geq 0$. However, in some industries process innovation could increase the cost of production. In that case, one should assume $f_I < 0$.

investment I for the intermediate product:

$$\max_{w, I} E\Pi^S = \underbrace{q_S(.)(w - (f_S - f_I)) - D(I)}_{\text{Forward profit}} \tag{11}$$

Note that in (11) q_S is equal to aggregate output of M which is $q = q_1 + q_2 + q_3$. This is because of the assumption that one unit of intermediate good will be used to make one unit of final good. Also, observe that q_S will be a function of I as q_2 is a function of I.

Table 1 exhibits the model notation covering 16 parameters, 11 variables, and 5 strategies.

Table 1: Model Notation

Players	**Description**
M, S	Firms M and S
$T1$,$T2$,$T3$	Customer types
Parameters	
α	Curtailment/take-back/return rate in market $T1$
ϵ_1	Rebate paid per unit of return
a_2	price cap in $T2$ market
b_2	demand sensitivity in $T2$ market
c_2	demand sensitivity to greenness in $T2$ market
θ	passive return quantity in $T2$ market
γ	return sensitivity to green investment in $T2$ market
a_3	price cap in $T3$ market
b_3	demand sensitivity in $T3$ market
c_M	cost of production parameter for M
d_I	the impact of innovation on cost of production
h_1	green investment cost parameter for S
e	marginal environmental impact of green investment
f_S	marginal cost of production for S
f_I	change in marginal cost due to green investment
p_1	price charged to $T1$ customers
Variables	
q_1	quantity sold to $T1$ customers
q_2	quantity sold to $T2$ customers
q_3	quantity sold to $T3$ customers
w	wholesale price chosen by S
I	green investment quantity chosen by S
p_2	price charged to $T2$ customers
p_3	price charged to $T3$ customers
r_1	return quantity in $T1$ market
r_2	return quantity in $T2$ market
Π^S, Π^M	profits for firms

4 Equilibrium Solution

While meeting demands of behavioral $T1$ and $T2$ customers in its jurisdiction, the manufacturer M competes with other manufacturers in wholesale market. The chain leader S has to figure out M's actions before choosing its price, because the manufacturer's strategies will impact the supplier's profit.

S knows that M will maximize the expected profit function in (8) which is

$$E\Pi^M(q_1, q_2, q_3) = q_1 p_1 + q_2 p_2(q_2, I) + q_3 Ep_3(Q) - C(q_1, q_2, q_3) + (r_1(q_1) + r_2(I))(Ep_3 - p_1 - \epsilon_1),$$

where the expected market price in market $T3$ is denoted by Ep_3. The last term, the backward activity profit, will drop out whenever the market price is unfavorable in the wholesale market. When this happens M will not withhold any output from the contract and green customers.

Before we examine the impact of the SDGs on CLSC strategies, we first examine a benchmark case by supposing what if any of these goals would not be pursued. In this benchmark there will be neither green investment nor development of a green product. This will impact customers' purchasing and return decisions, as the product will be viewed ordinary without any green attributes. Demand for the regular product will not be as much as demand for the green product. Also, the number of returns under benchmark scenario (in which product is normal) should be higher than the returns under implementation of SDGs (in which product is green). In addition, without investment and process innovation, production costs will not change for M and S. In this benchmark case, the inverse demand function for $T2$ customers in (3) will simplify to $p_2(q_2) = a_2 - b_2 q_2$, their return function in (5) will be passive and boil down to $r_2 = \theta$, and the coefficient of M's total production cost in (7) will change from $(c_M - d_I)$ to c_M, and it will modify from $(f_S - f_I)$ to f_S for S in (10). Consequently, we obtain the following.

Lemma 1: When the UN sustainability goals (7,9,12) are not implemented, the Stackelberg equilibrium strategies in the CLSC satisfy

$$q_{1,L1}(w) = \frac{p_1 - w_{L1} + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M}, \tag{12}$$

$$q_{2,L1}(w) = \frac{a_2 - w_{L1}}{2(c_M + b_2)}, \tag{13}$$

$$q_{3,L1}(w) = \frac{Ep_3 - w_{L1}}{2c_M}, where \tag{14}$$

$$w_{L1} = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M a_2}{2(2b_2 + 3c_M)}, \tag{15}$$

$$I_{L1} = 0 \tag{16}$$

Proof: See the Appendix.

The subscript "$L1$" refers to the outcome under the conditions of Lemma 1. Note that without investment the following parameters will be zero: $\gamma = e = c_2 = f_I = d_I = 0$. The investment cost in (9) satisfies $D(I) = 0$ as I is nil. Further, without investment there will not be process innovation nor will consumers form green consciousness and change their demand and return behavior.

To have positive outputs ($q_{1,L1}$, $q_{2,L1}$, $q_{3,L1} > 0$), the expected price in $T3$ market should be higher than the marginal cost of input ($Ep_3 > w_{L1}$), the maximum price in $T2$ market should be higher than the marginal cost of input ($a_2 > w_{L1}$), the price in $T1$ market plus the marginal benefit of curtailment should be higher than the marginal cost of input ($p_1 + \alpha(Ep_3 - p_1 - \epsilon_1) > w_{L1}$). Otherwise, the manufacturer has no incentive to produce.

When Goal 9 is not pursued so that the supplier neither invests in infrastructure nor carries out research and development (R&D) to innovate a green product (Goal 7), the product returns by $T2$ customers will be exogenous and independent of strategies. Specifically, when the supplier does not invest, the returns will be at a fixed rate θ for $T2$ type and be proportional to the consumption αq_1 for $T1$ type. $T2$ consumers will only relate their purchasing decisions to the price of the "regular product" (neither green nor clean) so that green consciousness is zero, that is $G = 0$. Furthermore, there will not be any cost advantage: the cost of production in the layers of the CLSC will not diminish ($f_I = d_I = 0$). Consequently, there will be neither an affordable product nor a green product if Goal 9 is not pursued.

Observe from Lemma 1 that the outputs decrease in wholesale price, decrease in cost of production, and increase in market potential and contract price. Furthermore, the price differential ($Ep_3 - p_1 - \epsilon_1$) will drop from the equilibrium strategies, if it is not positive. This is because there will not be any returns/curtailments from contract and green customers. However, whenever this term is positive, the output in $T1$ market increases in the price differential. This is because the curtailment/return quantity is proportional to the output in $T1$ market and higher output translates into higher returns. On the other hand, the outputs in $T2$ and $T3$ markets decrease in the price differential.

On the other hand, when the SDGs are implemented S can invest (Goal 9) to produce a green component and M can experience cost reduction causing affordability and completion of its green product (Goal 7). The end-users $T2$ react to the green product creation process and change their demand and return behavior (demand curve shifts and return function becomes green-sensitive), therefore $T2$ customers (in addition to $T1$ customers) will consume responsibly (Goal 12). Consequently, we obtain the following result.

Proposition 1: When the UN SDGs 7, 9, and 12 (leading to green investment, innovation, responsible consumption and production, and affordable green product) are implemented, the Stackelberg equilibrium strategies in the CLSC satisfy

$$q_{1,P1}(w) = \frac{p_1 - w_{P1} + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c}, \tag{17}$$

$$q_{2,P1}(w, I) = \frac{a_2 + c_2 e I_{P1} - w_{P1}}{2K_0}, \tag{18}$$

$$q_{3,P1}(w) = \frac{Ep_3 - w_{P1}}{2c}, \tag{19}$$

$$I_{P1}(w) = \frac{(w_{P1} - f)c_2 e}{2h_1 K_0}, where \tag{20}$$

$$w_{P1} = \frac{2h_1K_0[K_1 f + K_0(p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)) + ca_2] - cfc_2^2e^2}{4h_1K_1K_0 - cc_2^2e^2}, \tag{21}$$

where the constants are $c = (c_M - d_I)$, $f = (f_S - f_I)$, $K_0 = c + b_2$, and $K_1 = 3c + 2b_2$.

Proof: See the Appendix.

The subscript "$P1$" refers to the solution under the conditions of Proposition 1. The proof shows that the profit functions of both firms are strictly concave in strategies, therefore the equilibrium outcomes are unique.

The conditions warranting positive outputs in Lemma 1 are also sufficient to obtain positive outputs in Proposition 1. Furthermore, to have positive green investment, it is sufficient to have a higher wholesale price than the marginal cost of production with positive process innovation (i.e., $w_{P1} > f_S - f_I$). This is intuitive because when the price of the product exceeds the cost of making it and product demand increases in investment, the firm has an incentive to invest in research and development.

Observe from Proposition 1 that demand quantities across the customer types decrease in wholesale price w. Specifically, M's sale to $T1$ customers increase in its own price p_1 as well as in the price differential over the markets $T3$ and $T1$. As this price differential enlarges, it becomes more profitable for M to sell into $T3$ market, and M will curtail more quantity from $T1$ market. While the green investment made by S impacts all outputs (through cost reductions), it directly impacts $T2$ market where consumers are green-conscious and their demand increases in greenness level (eI) of the product. Further, the output in $T2$ market increases in demand intercept (a_2) and decreases in cost (c) and price sensitivity (b_2). Similarly, the output in $T3$ market increases in its price and decreases in costs. The equilibrium wholesale price increases in retail price. The downstream firm's marginal revenue curve becomes upstream firm's demand curve. Therefore, outputs in each vertical layer of supply chain decrease, and hence prices increase in both upstream and downstream. This creates a double markup problem, which is commonly observed in CLSC models (e.g., Genc and De Giovanni, 2017). In terms of returns/curtailments, $T1$ customers' return is proportional to their consumption as defined in the contract in (2), when the market price in $T3$ exceeds the price in $T1$ market plus the rebate per unit of curtailment. The return quantity in $T2$ market decreases in investment. Both $T1$ and $T2$ behavioral customers consume responsibly as they sacrifice from their consumption which will be diverted to $T3$ market consumers.

Note that while the green investment directly causes affordability and clean product, and responsible consumption, Goals 7 and 12 also impact the level of investment because of the backward activity and the sequential nature of decision making. That is, while I leads to increase in demand for green product, I increases in demand parameter c_2 in (3) and product greenness parameter e in (4). Further, the process innovation causing cost reductions (when f_I and d_I are positive) boosts the green investment: I increases in f_I and d_I. In addition, the green investment increases in wholesale price charged to the manufacturer. This will, in turn, increase the price of $T2$ consumers as they directly benefit from green product. Next we provide an example to quantify the outcomes with and without SDGs.

Example 1: Let the contract parameters in $T1$ market be $\alpha = 0.2$, $\epsilon = 0.05$, $p_1 = 1.2$, and in $T2$ market be $\theta = 0.2$, $\gamma = 0.1$, $a_2 = 2$, $b_2 = 1$, $c_2 = 0.1$. Also assume that $a_3 = 2$ and $b_3 = 0.1$ satisfy in $T3$ market. Also let the expected price or realized price in market $T3$ be $p_3 = 1.3$ so that the marginal benefit of collection for M is positive: $p_3 - p_1 - \epsilon = 0.05$. The cost parameters are $c_M = 1$, $d_I = 0.2$ for M and $f_S = 1$, $f_I = 0.1$ for S. The green investment and environmental impact parameters are $h_1 = 1$ and $e = 0.1$.

Solution of Example 1: With the critical parameters satisfying $c_2 = 0.1$, $e = 0.1$, the green consciousness is "low". The equilibrium outcomes under SDGs hold $w_{P1} = 1.14523$, $p_{2,P1} = 1.76257$, with the total output $q_{P1} = 0.37465$, the returns are $r_{1,P1} = 0.007302$ and $r_{2,P1} = 0.193012$, the investment is $I_{P1} = 0.00068$, and the profits are $\Pi^M_{P1} = 0.12027$ and $\Pi^S_{P1} = 0.09187$. Without the SDGs, the equilibrium outcomes hold the following: the prices are $w_{L1} = 1.202$, $p_{2,L1} = 1.8005$, the total cost of production for M is $C_{L1} = 0.34572$, the outputs are $q_{1,L1} = 0.004$, $q_{2,L1} = 0.1995$ and $q_{3,L1} = 0.049$ with the total $q_{L1} = 0.2525$, the returns are $r_{1,L1} = 0.0008$ and $r_{2,L1} = 0.2$, and the profits are $\Pi^M_{L1} = 0.09202$ and $\Pi^S_{L1} = 0.05101$.

In this example, (wholesale and retail) prices and total returns/curtailments are lower when the SDGs are implemented: $w_{P1} < w_{L1}$ and $p_{2,P1} < p_{2,L1}$ and $r_{1,P1} + r_{2,P1} < r_{1,L1} + r_{2,L1}$. But, profits and total outputs are higher $\Pi^M_{P1} > \Pi^M_{L1}$ and $\Pi^S_{P1} > \Pi^S_{L1}$ and $q_{P1} > q_{L1}$.

However, in the following example, the outcomes (prices, profits, outputs) are higher and the returns are lower when the SDGs are implemented.

Example 2: Keeping the rest of the parameters as is in Example 1, and changing only $c_2 = 1.2$, $e = 1.2$ (that is green consciousness is "high") and $d_I = 0$ and $f_I = 0.01$ (that is process innovation is "low"), we solve for Stackelberg equilibrium outcomes.

Solution of Example 2: We compute that $w_{P1} = 1.20832$, $p_{2,P1} = 1.886961$, with the total output $q_{P1} = 0.272897$, the returns are $r_{1,P1} = 0.000168$ and $r_{2,P1} = 0.192141$, the investment is $I_{P1} = 0.078594$, and the profits are $\Pi^M_{P1} = 0.114055$ and $\Pi^S_{P1} = 0.05649$. On the other hand, regardless of (c_2, e, d_I, f_I), the equilibrium outcomes without SDGs are that $w_{L1} = 1.202$, $p_{2,L1} = 1.8005$, with the total total $q_{L1} = 0.2525$, the returns $r_{1,L1} = 0.0008$ and $r_{2,L1} = 0.2$, and the profits $\Pi^M_{L1} = 0.09202$ and $\Pi^S_{L1} = 0.05101$.

In these examples, it is clear that profits, outputs, and investments are always higher under the implementation of the SDGs, however the ranking of prices is ambiguous. Next we will explain the source of this by taking a close look at the wholesale prices.

When all SDGs are applied to the CLSC, the wholesale price in Proposition 1 as a function of green investment is

$$w_{P1}(I) = \frac{(2b_2 + 3(c_M - d_I))(f_S - f_I) + ((c_M - d_I) + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + (c_M - d_I)(a_2 + c_2 eI)}{2(2b_2 + 3(c_M - d_I))}$$

When SDGs are not implemented we know from Lemma 1 that

$$w_{L1} = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M a_2}{2(2b_2 + 3c_M)}$$

Observe that in the numerator the first two terms when all SDGs are applied is lower than the ones when no SDGs are implemented. This is because $(c_M - d_I) < c_M$ and $(f_S - f_I) < f_S$, assuming positive process innovation. However, the third term could be higher or lower, because $(c_M - d_I) < c_M$ and $(a_2 + c_2 eI) > a_2$. The denominator of wholesale price in the proposition is clearly less than the one in the lemma. As a result, a smaller term is divided by another smaller term in Proposition 1 and a larger term is divided by another larger term in Lemma 1. On top of that, there is a positive investment term added to the wholesale price in Proposition 1. Consequently, the values of cost reduction parameters f_I and d_I and the product greenness parameters e and c_2 are critical to rank the wholesale prices above. Therefore, the wholesale prices will vary depending on those parameters.

To gain further insights, we will perform computational analysis to assess the benefits of SDGs.

5 Quantifying the Benefits of SDGs

In the previous section, we have analytically characterized Stackelberg equilibrium outcomes with and without SGDs. The strategies and profits are algebraically involved due to the complex relations between the model parameters. Further, the ranking of outcomes depends on certain parameter values, as shown in the examples. Therefore, we will carry out a numerical analysis, and compare and rank the outcomes with and without SDGs to gain further insights. Tables 2 and 3 report the corresponding equilibrium outcomes with respect to a wide range of key parameters. Tables 4 and 5 assess the benefits of SDGs and offer a sensitivity analysis for robustness.

The initial values of parameters are as follows. The contract parameters in $T1$ market are $\alpha = 0.1$, $\epsilon = 0.05$, $p_1 = 1.2$. Those in $T2$ market are $\theta = 0.2$, $\gamma = 0.1$, $a_2 = 2$, $b_2 = 1$, $c_2 = 0.1$. $T3$ market parameters are $a_3 = 2$ and $b_3 = 0.1$. The expected price in market $T3$ is $p_3 = 1.3$ so that the marginal benefit of collection for M is positive: $p_3 - p_1 - \epsilon = 0.05$. The cost parameters are $c_M = 1$, $d_I = 0.1$ for M and $f_S = 1$, $f_I = 0.1$ for S. The investment and environmental impact parameters are $h_1 = 1$ and $e = 0.1$.

These parameters which are also used in the above examples are chosen in a way that profit maximization conditions (the first and second order conditions) are satisfied and all equilibrium strategies are feasible. In the tables we perturb the initial parameter values over a certain range for robustness purpose. Some other parameters such as market potential are not perturbed. They are fixed at their initial values since they are non-essential and their impacts on strategies are intuitive.

Table 2 reports equilibrium outcomes (profits, prices, outputs, returns, investments) with respect to various levels of critical parameters when the SDGs are implemented. While we have run the calibrations with parameters spanning a wide range of intervals, we report only three values in their feasible sets to save space in columns. In addition, we observe that outcomes are monotonic in model parameters, therefore reporting a few parameter values and their corresponding outcomes is sufficient. In the rows, the green consciousness parameters are c_2 and e: profits, total outputs, prices, and investment monotonically increase in these parameters, while total returns/curtailments (r_{P1}) monotonically decrease. The positive process innovation parameters are f_I and d_I: profits, total outputs, total returns/curtailments, and investment monotonically increase in these parameters, while prices (w_{P1}, $p_{2,P1}$) monotonically decrease. The green investment cost parameter is represented by h_1. While higher green investment costs decrease the supplier's investments and profits, the manufacturer's outputs and profits marginally increase. This is because the returns increase and the wholesale price (w_{P1}) decreases. The return/curtailment rates are represented by the parameters α (curtailment rate for $T1$ customers) and γ (return rate with respect to green investment for $T2$ customers). The condition to curtail the product is ($p_3 - p_1 - \epsilon > 0$) which ensures positive returns and sales in $T3$ market. All outcomes (profits, total outputs, prices, returns, investments) monotonically increase in α and $p_3 - p_1 - \epsilon$. However, the impact of γ is minimal on outcomes and is only sensitive to $T2$ customer returns (and therefore to total number of returns) and manufacturer's profit. Also, the manufacturer's profit and total returns decrease in γ.

For the same parameter intervals used in Table 2, we exhibit equilibrium outcomes in the absence of SDGs in Table 3. The outcomes are only sensitive to return rate and curtailment condition for contract customers. In particular, the values of profits, prices, outputs, returns do not change with parameters (c_2, e, f_I, d_I, h_1, γ). However, they increase in α and $p_3 - p_1 - \epsilon$, similar to Table 2 results. Observe that the differential between total output (q) and total returns (r) is positive and sizable. This is because of M's incentive to sell in $T3$ market plus behavioral altruistic return behavior of $T1$ and $T2$ customers.

<Tables 2, 3>

Table 4 which is obtained by the findings in Tables 2 and 3 exhibits the value-added by the SDGs. It presents the signs of outcome differential when SDGs are implemented versus when they are not for each parameter value in its range. For instance, the term in the first column $\Pi^M_{P1} - \Pi^M_{L1}$ is the manufacturer's profit difference when SDGs are in place (Proposition 1, P1) versus when they are not (Lemma 1, L1). Specifically, the first positive sign in the first cell implies that the manufacturer's profit is always higher under SDGs (Π^M_{P1}) than under no SDGs (Π^M_{L1}) for the range of the first parameter (c_2), given that the values of other parameters are fixed at their initial values. This profit difference is always positive for all parameters. This shows that the manufacturer always earns higher profit under the implementation of SDGs. Further, investments, outputs, returns, profits are all higher (+ sign) and the prices are lower (- sign) under the SDGs. Consequently, we write the following claim.

Claim 1: Implementation of SDGs improves the welfare of society. Specifically, when SDGs are applied firms invest more and earn higher profits, consumers consume more, accept higher curtailments, and enjoy lower prices.

<Tables 4, 5>

In Table 5 we carry out sensitivity analysis by measuring the rate of change of equilibrium outcome differentials (outcome under SDGs minus outcome under no SDGs) with respect to change in parameter values. We find that the differentials of profits, outputs, prices, and investments increase in green consciousness parameters c_2 and e, while the difference of returns decreases in them. That is, the equilibrium outcomes with SDGs deviate from the ones without SDGs in favor of SDGs. Notation-wise, $\partial Y_1/\partial X_1 > 0$, where $Y_1 = \{\Pi^M_{P1} - \Pi^M_{L1}, \Pi^S_{P1} - \Pi^S_{L1}, q_{P1} - q_{L1}, w_{P1} - w_{L1}, p_{P1} - p_{L1}, I_{P1} - I_{L1}\}$, and $X_1 = \{c_2, e\}$, and $\partial(r_{P1} - r_{L1})/\partial X_1 < 0$.

This means that as the consumer consciousness for green products improves, the supplier invests more, and all firms produce more and earn higher profits. The consumers enjoy higher consumption and return less. These are all desirable outcomes as the supply chains generally aim to obtain these outcomes in their operations. This finding signifies the importance of implementing SDGs as a response to consumer green consciousness. Therefore, the best possible outcome can be obtained by pursuing the SDGs in supply chains. Consequently, we write the following claim.

Claim 2. As the consumer consciousness for green products rises, the equilibrium outcomes improve under the SDGs: the firms invest more, produce more, and earn higher profits; the consumers enjoy higher consumption and return less.

In addition, profit, output, investment, and return differentials also deviate in favor of SDGs as the industry experiences more process innovation (represented by the process innovation parameters f_I and d_I). The price differentials will be weakly decreasing in innovation parameters. Notation-wise, $\partial Y_2/\partial X_2 > 0$, where $Y_2 = \{\mathit{\Pi}_{P1}^M - \mathit{\Pi}_{L1}^M,\, \Pi_{P1}^S - \Pi_{L1}^S,\, q_{P1} - q_{L1},\, I_{P1} - I_{L1},\, r_{P1} - r_{L1}\}$ and $X_2 = \{f_I,\, d_I\}$, and $\partial(p_{2,P1} - p_{2,L1})/\partial X_2 < 0$ and $\partial(w_{P1} - w_{L1})/\partial X_2 \leq 0$. This implies the following claim.

Claim 3. As the industry becomes more innovative in creating green products, the supply chain firms enjoy higher profits supported by higher outputs, investments, returns and lower prices in the presence of SDGs.

As the investment cost increases (represented by rising h_1) the benefits of SDGs diminish. This is because total output, investment, prices, and the supplier's profit approach to the ones when SDGs are not implemented. However, the manufacturer's profit differential still increases in h_1 because its input price differential reduces and the return differential goes up. Notation-wise, $\partial Y_3/\partial X_3 < 0$, where $Y_3 = \{\Pi_{P1}^S - \Pi_{L1}^S,\, q_{P1} - q_{L1},\, I_{P1} - I_{L1},\, p_{2,P1} - p_{2,L1},\, w_{P1} - w_{L1}\}$ and $X_3 = \{h_1\}$, and $\partial(\mathit{\Pi}_{P1}^M - \mathit{\Pi}_{L1}^M)/\partial X_3 > 0$ and $\partial(r_{P1} - r_{L1})/\partial X_3 > 0$. Therefore, we claim the following.

Claim 4. If the green technology investment costs rise, then the benefits of implementing SDGs may disappear.

As the curtailment rate α and/or the price differential $p_3 - p_1 - \epsilon$ leading to curtailment go up, the benefits of SDGs rise: profits, total output, investment, and prices deviate from those without SDGs. Moreover, the return differential increases in curtailment rate and decreases in curtailment condition. Notation-wise, $\partial Y_4/\partial X_4 > 0$, where $Y_4 = \{\mathit{\Pi}_{P1}^M - \mathit{\Pi}_{L1}^M,\, \Pi_{P1}^S - \Pi_{L1}^S,\, q_{P1} - q_{L1},\, I_{P1} - I_{L1},\, w_{P1} - w_{L1},\, p_{2,P1} - p_{2,L1}\}$, and $X_4 = \{\alpha, p_3 - p_1 - \epsilon\}$, and $\partial(r_{P1} - r_{L1})/\partial\alpha > 0$ and $\partial(r_{P1} - r_{L1})/\partial(p_3 - p_1 - \epsilon) < 0$.

This implies that product returns will provide more benefits to the stakeholders when SDGs are implemented. When the contract customers accept more returns (higher α) all firms will earn more profits because prices and aggregate consumption will further go up under SDGs. This also provides benefits to the consumers because they will increase their demand and consume more green products. Consequently, we propose the following claim.

Claim 5. When the curtailment price condition is satisfied and the curtailment rate increases, the supply chain obtains more benefits for implementing SDGs.

The rate of change of outcome differential with respect to γ, representing the return response rate of $T2$ customers to green investment, is non-positive and minimal compared to the impact of other model parameters. It mainly affects the manufacturer's profit and total return. As this rate goes up, the outcomes with SDGs converge to the outcomes without SDGs. Notation-wise, $\partial Y_5/\partial X_5 \leq 0$, where $Y_5 = \{\mathit{\Pi}^M_{P1} - \mathit{\Pi}^M_{L1}, \Pi^S_{P1} - \Pi^S_{L1}, q_{P1} - q_{L1}, r_{P1} - r_{L1}, w_{P1} - w_{L1}, p_{2,P1} - p_{2,L1}, I_{P1} - I_{L1}\}$ and $X_5 = \{\gamma\}$. Based on this finding we write the following.

Claim 6. The manufacturer prefers lower green consumer return response rate in the presence of SDGs, although the rate of change in supply chain outcome differentials with respect to the change in green consumer return response rate is minimal (the derivative is zero for the most outcome differentials).

6 Partial Implementation of SDGs

One way of examining impact of a specific SDG is to exclude one of them and perform the analysis with the rest. Alternatively, it could happen that a subset of these goals would be targeted and/or be available. The relevant cases involve a) application of Goal 9 and Goal 12 together; and b) application of Goals 9 and 7 simultaneously. In any of these cases, Goal 9 is critical and will cause other goal to be achieved.

Proposition 2: When Goals 9 and 12 are implemented together, that is, the sustainability goals aim green investment and responsible consumption, we obtain the following in equilibrium.

$$w_{P2} = \frac{2h_1K_2[K_3f_S + K_2(p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)) + c_Ma_2] - c_Mf_Sc_2^2e^2}{4h_1K_2K_3 - c_Mc_2^2e^2} \quad (22)$$

$$I_{P2}(w) = \frac{(w_{P2} - f_S)c_2e}{2h_1(c_M + b_2)} \quad (23)$$

$$q_{1,P2}(w) = \frac{p_1 - w_{P2} + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M} \quad (24)$$

$$q_{2,P2}(w, I) = \frac{a_2 + c_2eI_{P2} - w_{P2}}{2(c_M + b_2)} \quad (25)$$

$$q_{3,P2}(w) = \frac{Ep_3 - w_{P2}}{2c_M} \quad (26)$$

where the constants are $K_2 = c_M + b_2$, and $K_3 = 3c_M + 2b_2$.

Proof: See the Appendix.

When green investment causes responsible consumption/production so that investment is strategic and leads to endogenous return behavior, the equilibrium strategies are presented in Proposition 2. Note that this proposition separates the impact of Goal 9 on Goal 12 from that of Goal 9 on Goal 7. Under the conditions of Proposition 2, the affordable product goal is not pursued. Therefore, the cost parameters $f_I = d_I = 0$ hold (i.e., there is no cost reduction effect of green investment), and the parameters related to responsible consumption will be positive, c_2, h_1, e, $\gamma > 0$ (some consumers respond positively to green product investment and adjust their returns accordingly).

As discussed in the literature section, the effect of Goal 9 on Goal 12 is to aim fostering returns and sales which is part of "strategic lean" initiatives. Under the conditions of Proposition 2, the supplier's investment creates demand for green product. While only $T2$ consumers are green-conscious and increase their demand, other customer types $T1$ and $T3$ are also affected albeit they are not necessarily green-conscious. Both firms S and M will raise their prices, hence the average consumer price will go up, while green product will increase the utility of $T2$ consumers.

Proposition 3: Assume that firms implement Goals 9 and 7 pertaining to green investment and affordable green product. If consumers do not react to the industry green investment and do not change their consumption and return behavior, the following Stackelberg equilibrium outcomes hold:

$$w_{P3} = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M a_2}{2(2b_2 + 3c_M)} \quad (27)$$

$$I_{P3} = 0 \quad (28)$$

$$q_{1,P3}(w) = \frac{p_1 - w_{P3} + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M} \quad (29)$$

$$q_{2,P3}(w) = \frac{a_2 - w_{P3}}{2(c_M + b_2)} \quad (30)$$

$$q_{3,P3}(w) = \frac{Ep_3 - w_{P3}}{2c_M} \quad (31)$$

Proof: See the Appendix.

If the green investment aims process innovation only, so that production costs (of intermediate and final products) go down, but consumers do not react to this investment and do not change their consumption and return behavior, then the supplier should choose not to invest in equilibrium. That is, when the consumers do not respond to the green efforts in the supply chain, implying that Goal 12 is not pursued by the consumers, S should not invest at all.

One reason why the consumers do not react to green product developments could be that the green-conscious consumers were not convinced with greenness level of the product, measured by c_2: they might believe that these investments were essentially intended to mitigate firms' operational expenditures. Therefore, they would ignore Goal 9 in the CLSC, and perceive the product as a "regular product". Given this consumer behavior, the supplier should not invest.

Notation-wise, it holds that $c_2 = 0$, that is $T2$ consumers do not respond to product greenness. Also, this behavior will reflect on product returns and $T2$ customers will be passive in returns so that $\gamma = 0$ will hold in its return function in (4). That is, $T2$ customers will discard the new product effort. Therefore, the green-conscious consumers will be dissatisfied with the price they pay for the product and the total rebates they receive for returns. Specifically, $T2$ customer inverse demand will reduce to $p_2(q_2) = a_2 - b_2 q_2$ and their return function will boil down to $r_2 = \theta$.

Because the green investment is nil, no process innovation occurs in equilibrium. In addition, production costs in both layers of the CLSC will not decrease. Consequently, the Stackelberg equilibrium prices and the outputs in Proposition 3 will be identical to the ones in Lemma 1.

We can analytically compare Proposition 2 to Lemma 1 to emphasize the role of responsible consumption (Goal 12) on supply chain outcomes.

Proposition 4: Comparing the equilibrium outcomes with sustainability goals of industry green investment and responsible consumption/production (Proposition 2) to the outcomes without any sustainability goals (Lemma 1) yields the following:

a) The upstream wholesale prices compare $w_{P2} > w_{L1}$,

b) The downstream prices compare $p_{2,P2} > p_{2,L1}$ in market $T2$, $p_{1,P2} = p_{1,L1}$ in market $T1$, and $p_{3,P2} = p_{3,L1}$ in market $T3$.

c) The outputs in the respective markets satisfy $q_{2,P2} > q_{2,L1}$ and $q_{1,P2} < q_{1,L1}$ and $q_{3,P2} < q_{3,L1}$.

d) Investments compare $I_{P2} > I_{L1} = 0$.

e) Returns are lower under the SDGs: $r_{1,P2} < r_{1,L1}$ and $r_{2,P2} < r_{2,L1}$.

f) Profits are higher under the SDGs: $\Pi^M_{P2} > \Pi^M_{L1}$ and $\Pi^S_{P2} > \Pi^S_{L1}$.

Proof. See the Appendix.

As detailed in the proof, the lower bounds of outputs, prices, and profits under the SDGs (9 and 12) are obtained when the green investment (I_{P2}) approaches zero. As it goes down to zero, the upstream wholesale price under the SDGs approaches to the price under no sustainability program: $\lim_{I_{P2}\to 0} w_{P2} = w_{L1}$.

This opens up the following question: under what conditions does S invest "too little"? The equilibrium green investment would approach zero when green consciousness is low so that consumers care "too little" about the green attributes of the product (that is $c_2 \to 0$) and/or the environmental benefit of the product is low (that is $e \to 0$). In either case, the equilibrium investment will converge to zero and therefore, the wholesale price under SDGs would approach to the one in the absence of SDGs.

Because wholesale price the in upstream will be an input cost in the downstream, outputs in markets $T1$ and $T3$ will be lower with the implementation of SDGs: $q_{1,P2} < q_{1,L1}$ and $q_{3,P2} < q_{3,L1}$. However, in market $T2$, $q_{2,P2} > q_{2,L1}$ must hold because the investment is a demand shifter. Furthermore, $\lim_{I_{P2}\to 0} q_{2,P2} = q_{2,L1}$ and $\partial q_{2,P2}/\partial I_{P2} > 0$ hold.

The retail prices with and without SDGs are identical because of M's contract with $T1$ customers and the fringe status of M in market $T3$. On the other hand, in market $T2$ the manufacturer produces more and charges a higher price because its demand shifts upward when it invests. Therefore, $q_{2,P2} > q_{2,L1}$ and $p_{2,P2} > p_{2,L1}$.

In terms of returns, consumers will hold on to the product as much as possible and will return less under the SDGs. In market $T1$, the returns directly follow from outputs, nevertheless the returns in market $T2$ are functions of the green investment: the higher the green investment the lower the return is.

Implementing the SDGs pays off: both M and S increase their profits when they engage in sustainability programs. The proof of this result comes from the finding that when the green investment approaches zero, all outputs and prices with SDGs will converge to the ones without SDGs. Therefore, the profits will be equal under both cases in the limit. Furthermore, the profit of each firm is increasing in the amount of green investment. Consequently, firms fare better under the SDGs. In other words, $\lim_{I_{P2}\to 0} \Pi^S_{P2} = \Pi^S_{L1}$ holds using the limit argument. Furthermore, Π^S_{P2} is concave in investment I_{P2} as it gets its maximum in Proposition 2. Therefore, an incremental investment by S together with consumer consciousness result in higher profit. Similar arguments also apply to M's profit.

7 Conclusions

The novelty of this paper is threefold: a) an implementation of the UN SDGs into a CLSC framework involving green product development; b) formulating product returns as demand curtailments through contracts; c) consideration of behavioral consumers (with green consciousness and altruism) along with a variety of pricing options.

In addition to having a tractable two-echelon supply chain framework involving a supplier (S) and a manufacturer (M) who are interlinked through vertical relations, we introduce a pseudo-market with many manufacturers in the downstream to justify the wholesale market. The manufacturer (M) competes with them for the wholesale market customers ($T3$) while meeting the demands of behavioral $T1$ and $T2$ consumers. Furthermore, as S and M execute the UN SDGs of 7 and 9, $T1$ and $T2$ type consumers respond to these SDGs and fulfill Goal 12 of "responsible consumption" through returns/curtailments. While $T1$ and $T2$ consumers are altruistic in consumption, they are rewarded via rebates. Given that the intermediate product maker (S) invests in green component and the final product maker (M) produces green product, firms can exploit green consciousness and price-discriminate, and hence increase their profits. Consumers also increase their utilities through green product consumption and rebates. Consequently, the UN SDGs provide benefits to the CLSC participants by increasing welfare and reducing waste.

Actual industry examples parallel to our CLSC framework could include several sectors such as food, energy, automobile, and garment. For example, regarding electricity industry, S could produce wind turbine blade, nacelle, or generator and M would produce green electricity from wind generation. M could face different types of consumers including green customers who are environmentally conscious and buy green electricity only. M might also sell power in the wholesale electricity market where it would face competition. For automobile sector, S could refer to Panasonic producing battery for Tesla which is the manufacturer of the electric car, say Model X. While Tesla meets demand for electric car, it also competes with other car makers in the sector. For garment sector, a supplier of organic cotton which is grown using methods that have a low impact on the environment sells it to a firm, say H&M, who produces and sells organic cotton based clothing. While meeting demand for "green clothing", the H&M also competes with other garment producers in the industry.

The paper could be extended in several directions. First, one could extend the one-shot Stackelberg competition framework to multiple periods so as to reveal the long-term impacts of the SDGs for consumers, producers, and the environment. Second, one could allow competition in both upstream and downstream as firms may compete with others in a given layer of CLSC. Alternatively, in order to deal with effective product management issues one could expand the number of tiers inthe CLSC. Third, even though the current model identifies and examines three types of SDGs, some other SDGs may also be relevant for CLSCs. Fourth, one could introduce sophisticated green-conscious consumers with memory, responding to past (and present) activities of the upstream supplier. These extensions could bring about further insights for understanding the effects of sustainable development programs in supply chains in the presence of behavioral consumers.

References

[1] Chavez, R., Yu, W., Jacobs, M., Fynes, B., Wiengarten, F., & Lecuna, A. (2015). Internal lean practices and performance: The role of technological turbulence. International Journal of Production Economics, 160, 157-171.

[2] De Giovanni, P.; Reddy, P. V. & Zaccour, G. (2016). Incentive strategies for an optimal recovery program in a closed-loop supply chain. European Journal of Operational Research 249(2), 605–617.

[3] De Giovanni, P. (2017). Closed-loop supply chain coordination through incentives with asymmetric information. Annals of Operations Research 253(1), 133–167.

[4] Fliedner, G., & Majeske, K. (2010). Sustainability: the new lean frontier. Production and Inventory Management Journal, 46(1), 6-13.

[5] Genc, T. S., and De Giovanni, P. (2021). Dynamic pricing and green investments under conscious, emotional, and rational consumers. Cleaner and Responsible Consumption. https://doi.org/10.1016/j.clrc.2021.100007.

[6] Genc, T. S., and De Giovanni, P. (2020). Closed-loop supply chain games with innovation-led lean programs and sustainability. International Journal of Production Economics, 219: 440-456.

[7] Genc, T. S., and De Giovanni, P. (2017). Trade-in and save: A two-period closed-loop supply chain game with price and technology dependent returns. International Journal of Production Economics, 183, 514-527.

[8] Genc, T.S. (2017). The Impact of Lead Time on Capital Investments. Journal of Economic Dynamics and Control, 82:142-164.

[9] Gimenez C. and Sierra V.R.J. (2012). Sustainable Operations: Their Impact on the Triple Bottom Line. International Journal of Production Economics, 140: 149–159.

[10] Gino, F., Pisano, G. (2008). Toward a theory of behavioral operations. Manufacturing Service Operations Management, 10(4):676-691.

[11] Gotschol A, De Giovanni P., Vinzi VE. (2014). Is Environmental Management an Economically Sustainable Business? Journal of Environmental Management; 144: 73–82.

[12] Govindan, K., H. Soleimani, D. Kannan (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. European Journal of Operational Research, 240, 603-626.

[13] Guide Jr, V. D. R. & Van Wassenhove, L. N. (2009). The evolution of closed-loop supply chain research. Operations Research 57(1), 10–18.

[14] Hong, X.; Govindan, K.; Xu, L. & Du, P. (2017), 'Quantity and collection decisions in a closed-loop supply chain with technology licensing', European Journal of Operational Research 256(3), 820–829.

[15] Jasti N. and Kodali, R. (2015). Lean production: literature review and trends. International Journal of Production Research, 53:3, 867-885

[16] Kaya, O. (2010). Incentive and production decisions for remanufacturing operations. European Journal of Operational Research 201(2), 442–453.

[17] Kobayashi, S. (2015). On a dynamic model of cooperative and noncooperative R and D in oligopoly with spillovers. Dynamic Games and Applications, 5(4), 599-619.

[18] Laroche, M., Bergeron, J., & Barbaro-Forleo, G. (2001). Targeting consumers who are willing to pay more for environmentally friendly products. Journal of Consumer Marketing, 18(6), 503-520.

[19] Loch, C. H., Wu, Y. (2007). Behavioral operations management, foundation and trends. Delft, the Netherlands.

[20] Martinez-Jurado PJ, Moyano-Fuentes J. (2013). Lean Management, Supply Chain Management and Sustainability: A Literature Review. J Clean. Prod.; 85: 134–150.

[21] Rothenberg, S., Pil, F. K., and Maxwell, J. (2001). Lean, green, and the quest for superior environmental performance. Production and Operations Management, 10(3), 228-243.

[22] Sauer, P. C., S. Seuring. (2019). Extending the reach of multi-tier sustainable supply chain management- insights from mineral supply chain. International Journal of Production Economics, 217:31-43.

[23] Savaskan, R. C.; Bhattacharya, S. & Van Wassenhove, L. N. (2004), 'Closed-loop supply chain models with product remanufacturing', Management Science 50(2), 239-252.

[24] Wilhelm, M., Blome, C., Wieck, E., Xiao, C.Y. (2016). Implementing sustainability in multi-tier supply chains. Strategies and contingencies in managing sub-suppliers. International Journal of Production Economics 182:196-212.

[25] Yang, M. G. M., Hong, P., and Modi, S. B. (2011). Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. International Journal of Production Economics, 129(2), 251-261.

Appendix

Proof of Proposition 1: Assuming that all three goals (of 7,9, and 12) are executed the optimality conditions are as follows.

The first order necessary condition with respect to optimal output in market $T1$ is $\frac{\partial E\Pi^M}{\partial q_1} = p_1 - 2(c_M - d_I)q_1 - w + \alpha(Ep_3 - p_1 - \epsilon_1) = 0$. The second order condition satisfies $\frac{\partial^2\Pi^M}{\partial q_1^2} = -2(c_M - d_I) < 0$ because $c_M - d_I > 0$ by assumption. This implies

$$q_1(w, Ep_3) = \frac{p_1 - w + \alpha(Ep_3 - p_1 - \epsilon_1)}{2(c_M - d_I)} \tag{32}$$

The expected profit maximizing level of production in market $T2$ satisfies $\frac{\partial E\Pi^M}{\partial q_2} = a_2 - 2b_2q_2 + c_2eI - 2(c_M - d_I)q_2 - w = 0$. The second order condition satisfies $\frac{\partial^2\Pi^M}{\partial q_2^2} = -2(b_2 + c_M - d_I) < 0$ because $c_M - d_I > 0$ and $b_2 > 0$ by assumption. This implies

$$q_2(w, I) = \frac{a_2 + c_2 eI - w}{2(c_M - d_I) + 2b_2} \tag{33}$$

In the wholesale market $T3$, the optimal output satisfies $\frac{\partial E\Pi^M}{\partial q_3} = Ep_3 - 2(c_M - d_I)q_3 - w = 0$. The second order condition is $\frac{\partial^2 \Pi^M}{\partial q_3^2} = -2(c_M - d_I) < 0$ because $c_M - d_I > 0$ by assumption. This implies

$$q_3(w, Ep_3) = \frac{Ep_3 - w}{2(c_M - d_I)} \tag{34}$$

The outputs in (31)-(33) are the best response functions of M for a given level of wholesale price w and the investment I chosen by S to satisfy the Goal 9. Observe that the Goal 7 leads to higher outputs in the respective customer groups.

In the upstream layer of the industry, given the production strategies of M, S will maximize its profit function in (11) to choose its investment level (Goal 9) as well as its wholesale price, which will be affected by the SGs in the CLSC:

$$\underset{w,\, I}{max}\Pi^S = (q_1(w) + q_2(w,\, I) + q_3(w))(w - (f_S - f_I)) - D(I)$$

The first order necessary condition with respect to wholesale price is $\frac{\partial \Pi^S}{\partial w} = (w - (f_S - f_I))[-2/2(c_M - d_I) - 1/(2(c_M - d_I) + 2b_2)] + (q_1(w) + q_2(w,\, I) + q_3(w)) = 0$. The second order condition is $\frac{\partial^2 \Pi^S}{\partial w^2} = -[6(c_M - d_I) + 4b_2]/[4(c_M - d_I)(c_M - d_I + b_2)] < 0$ because $c_M - d_I > 0$ by assumption. Here the total output produced by the S or the M in all markets is

$$\sum_{i=1}^{3} q_i(w, I) = \frac{(c_M - d_I + b_2)[p_1 + Ep_3 - 2w + \alpha(Ep_3 - p_1 - \epsilon_1)] + (c_M - d_I)[a_2 + c_2 eI - w]}{2(c_M - d_I)(c_M - d_I + b_2)} \tag{35}$$

Then the equilibrium wholesale price as a function of the "green investment" is

$$w(I) = \frac{(2b_2 + 3(c_M - d_I))(f_S - f_I) + ((c_M - d_I) + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + (c_M - d_I)(a_2 + c_2 eI)}{2(2b_2 + 3(c_M - d_I))} \tag{36}$$

Observe that the wholesale price is increasing in the expected price (Ep_3) charged to the wholesale market customers $T3$, and increasing in greenness level of the product (eI), defined in expression (9).

The profit maximizing level of green investment satisfies

$\frac{\partial \Pi^S}{\partial I} = (w - (f_S - f_I))\frac{\partial q_2}{\partial I} - h_1 I = 0$

The second order condition satisfies $\frac{\partial^2 \Pi^S}{\partial I^2} = -h_1 < 0$ because $h_1 > 0$ by assumption. This implies

$$I(w) = \frac{(w - (f_S - f_I))c_2 e}{2h_1(c_M - d_I + b_2)} \tag{37}$$

Solving (35) and (36) together we obtain Stackelberg equilibrium wholesale price and investment as a function of model parameters.

The expression in (35) becomes

$$w = \frac{2h_1 K_0[K_1 f + K_0(p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)) + ca_2] - cfc_2^2 e^2}{4h_1 K_1 K_0 - cc_2^2 e^2} \tag{38}$$

where $c = (c_M - d_I)$, $f = (f_S - f_I)$, $K_0 = c + b_2$, and $K_1 = 3c + 2b_2$.

Note that the equilibrium wholesale price w charged to the manufacturer increases in retail prices.

Proof of Lemma 1:

This case boils down to involve no investment, $I = 0$, because the Goal 9 is not pursued. Then, demand, return, and cost functions reach to their reduced forms as such the following model parameters become zero: $\gamma = c_2 = e = f_I = d_I = 0$. Furthermore, $h_1 = 0$ which is implied by zero investment cost so that $D(I) = 0$.

Inserting these parameter values into the equilibrium conditions in the proof of Proposition 1 we obtain that

$$q_1(w) = \frac{p_1 - w + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M}$$

The production for the second market is

$$q_2(w) = \frac{a_2 - w}{2(c_M + b_2)}$$

In the market C_3, the optimal output is

$$q_3(w) = \frac{Ep_3 - w}{2c_M}.$$

The total output produced for all markets is

$$\sum_{i=1}^{3} q_i(w) = \frac{(c_M + b_2)[p_1 + Ep_3 - 2w + \alpha(Ep_3 - p_1 - \epsilon_1)] + (c_M)[a_2 - w]}{2(c_M)(c_M + b_2)} \tag{39}$$

When S does not invest its objective function becomes

$$\underset{w}{max} \Pi^S = (q_1(w) + q_2(w) + q_3(w))(w - f_S)$$

The first order necessary condition with respect to the wholesale price is

$\frac{\partial \Pi^S}{\partial w} = (w - f_S)[-2/2c_M - 1/2(c_M + b_2] + (q_1(w) + q_2(w) + q_3(w)) = 0$

which implies that

$$w = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M a_2}{2(2b_2 + 3c_M)}$$

Hence, the result. □

Proof of Proposition 2:

When the investment (Goal 9) provides benefit only to returns and demand so that the Goal 12 is satisfied, all model parameters will be positive but $f_I = d_I = 0$, which are the cost improvement parameters. Inserting these parameters into the equilibrium outcomes in the proof of Proposition 1 we obtain that in the $T1$ market

$$q_1(w, Ep_3) = \frac{p_1 - w + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M}$$

The expected profit maximizing level of production in market $T2$ satisfies

$$q_2(w, I) = \frac{a_2 + c_2 eI - w}{2(c_M + b_2)}$$

In the wholesale market $T3$, the optimal output satisfies

$$q_3(w, Ep_3) = \frac{Ep_3 - w}{2c_M}$$

In the upstream layer of the industry, the equilibrium wholesale price as a function of the "green investment" is

$$w(I) = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M(a_2 + c_2 eI)}{2(2b_2 + 3c_M)}$$

The profit maximizing level of innovation satisfies

$\frac{\partial \Pi^S}{\partial I} = (w - f_S)\frac{\partial q_2}{\partial I} - h_1 I = 0$

which implies

$$I(w) = \frac{(w - f_S)c_2 e}{2h_1(c_M + b_2)}$$

Inserting this investment function into the wholesale price results in

$$w = \frac{2h_1 K_2[K_3 f_S + K_2(p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)) + ca_2] - c_M f_S c_2^2 e^2}{4h_1 K_2 K_3 - c_M c_2^2 e^2}$$

where $K_2 = c_M + b_2$, and $K_3 = 3c_M + 2b_2$.

Proof of Proposition 3:

M will maximize its expected profit function:

$$E\Pi^M(q_1, q_2, q_3) = q_1 p_1 + q_2 p_2(q_2) + q_3 Ep_3(Q) - C(q_1, q_2, q_3) + (r_1(q_1) + r_2(I))(Ep_3 - p_1 - \epsilon_1)$$

The first order necessary condition with respect to output in market $T1$ is

$\frac{\partial E\Pi^M}{\partial q_1} = p_1 - 2(c_M - d_I)q_1 - w + \alpha(Ep_3 - p_1 - \epsilon_1) = 0$

This condition implies

$$q_1(w, Ep_3) = \frac{p_1 - w + \alpha(Ep_3 - p_1 - \epsilon_1)}{2(c_M - d_I)}$$

The expected profit maximizing level of production in market $T2$ satisfies

$\frac{\partial E\Pi^M}{\partial q_2} = a_2 - 2b_2 q_2 - 2(c_M - d_I)q_2 - w = 0$

which implies

$$q_2(w) = \frac{a_2 - w}{2(c_M - d_I) + 2b_2}$$

In the wholesale market $T3$, the optimal output satisfies

$\frac{\partial E\Pi^M}{\partial q_3} = Ep_3 - 2(c_M - d_I)q_3 - w = 0$

which implies

$$q_3(w, Ep_3) = \frac{Ep_3 - w}{2(c_M - d_I)}$$

Given the production strategies of M, S will maximize its profit function:

$$\underset{w,\, I}{max} \Pi^S = (q_1(w) + q_2(w) + q_3(w))(w - (f_S - f_I)) - D(I)$$

The first order necessary condition with respect to wholesale price is

$\frac{\partial \Pi^S}{\partial w} = (w - (f_S - f_I))[-2/2(c_M - d_I) - 1/(2(c_M - d_I) + 2b_2)] + (q_1(w) + q_2(w,\, I) + q_3(w)) = 0$

where the total output in all markets is

$$\sum_{i=1}^{3} q_i(w) = \frac{(c_M - d_I + b_2)[p_1 + Ep_3 - 2w + \alpha(Ep_3 - p_1 - \epsilon_1)] + (c_M - d_I)[a_2 - w]}{2(c_M - d_I)(c_M - d_I + b_2)}.$$

Then the equilibrium wholesale price as a function of the "green investment" is

$$w = \frac{(2b_2 + 3(c_M - d_I))(f_S - f_I) + ((c_M - d_I) + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + (c_M - d_I)(a_2)}{2(2b_2 + 3(c_M - d_I))}$$

Observe that the wholesale price is increasing in the expected price (Ep_3) charged to the wholesale market customers.

The profit maximizing level of innovation satisfies

$\frac{\partial \Pi^S}{\partial I} = -h_1 I < 0$

which implies $I = 0$.

No investment by the supplier will imply that the CLSC will experience no cost reductions. Therefore, the cost coefficients will be $d_I = f_I = 0$. Consequently the result in the proposition holds.

Proof of Proposition 4:

When the industry innovation (i.e., investment) only impacts returns and demand (Proposition 2), so that the production costs are intact, the following parameters will be zero: $f_I = d_I = 0$. Clearly c_2, h_1, $e > 0$ which are demand and investment function coefficients.

At $f_I = d_I = 0$ the wholesale price in (21) gets

$$w_{P2}(I) = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M(a_2 + c_2 eI_{P2})}{2(2b_2 + 3c_M)}$$

When SDGs are not implemented we know from Lemma 1 that

$$w_{L1} = \frac{(2b_2 + 3c_M)f_S + (c_M + b_2)[p_1 + Ep_3 + \alpha(Ep_3 - p_1 - \epsilon_1)] + c_M a_2}{2(2b_2 + 3c_M)}$$

Clearly $w_{P2} > w_{L1}$ because $I_{P2} > 0$ in Proposition 2, and c_2, $e > 0$, and p_1 is fixed at the contract, and Ep_3 is the same market shock in both cases.

As the wholesale price is higher in the upstream, downstream prices will also be higher because output prices increase in input prices. Alternatively, when SDGs are not applied, the outputs satisfy, as in Lemma 1,

$$q_{1,L1}(w) = \frac{p_1 - w_{L1} + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M}$$

The production for the second market is

$$q_{2,L1}(w) = \frac{a_2 - w_{L1}}{2(c_M + b_2)}$$

In the third market the optimal output is

$$q_{3,L1}(w) = \frac{Ep_3 - w_{L1}}{2c_M}.$$

When the investment is strategic so that it benefits the demand and returns in market C_2, we obtain

$$q_{1,P2}(w) = \frac{p_1 - w_{P2} + \alpha(Ep_3 - p_1 - \epsilon_1)}{2c_M}$$

$$q_{2,P2}(w, I) = \frac{a_2 + c_2 eI_{P2} - w_{P2}}{2(c_M + b_2)}$$

$$q_{3,P2}(w) = \frac{Ep_3 - w_{P2}}{2c_M}$$

Because $w_{P2}(I) > w_{L1}$ and $I_{P2} > 0$ we obtain that
$q_{1,L1} > q_{1,P2}$ and $q_{3,L1} > q_{3,P2}$. Therefore, the M produces less in markets $T1$ and $T3$. As M is a

price taker in market $T3$ and already set the price in market $T1$ through contract, prices p_1 and p_3 will be intact.

However, the M will produce more and charge a higher price when it invests because this shifts demand upward. Therefore, $q_{2,P2} > q_{2,L1}$ and $p_{2,P2} > p_{2,L1}$. Alternatively, as wholesale price increases, that is $w_{P2} > w_{L1}$, the retail price goes up $p_{2,P2} > p_{2,L1}$ too.

An alternative proof to show that $q_{2,P2} > q_{2,L1}$ is as follows:

It holds that $\lim_{I_{P2} \to 0} q_{2,P2} = q_{2,L1}$ and $\partial q_{2,P2}/\partial I_{P2} > 0$, that is the output with SDGs is increasing in investment and the lower bound of output with SDGs approaches the output without SDGs, therefore $q_{2,P2} > q_{2,L1}$ must hold.

The result with respect to returns directly follows from the ranking of outputs in $T1$ market (higher output higher returns) and investment ranking in $T2$ market (higher investment lower returns).

Finally, using the limit argument $\lim_{I_{P2} \to 0} \Pi^S_{P2} = \Pi^S_{L1}$ furthermore Π^S_{P2} is concave in investment I_{P2} as it gets its maximum in Proposition 2. Therefore, an incremental investment by S under the SDGs would lead its profit to go up. Similar arguments also hold for M. $\square$

Table 2: Equilibrium Performance with SDGs

	$\mathit{\Pi}_{P1}^{M}$	Π_{P1}^{S}	q_{P1}	r_{P1}	w_{P1}	$p_{2,P1}$	I_{P1}
c_2 :(.1;.7;1)	.112893 .11294 .11299	.0844 .08441 .08442	.34057 .34061 .34066	.20311 .20272 .20252	1.14782 1.14785 1.14788	1.7757 1.776 1.7762	.00065 .00457 .00652
e:(.1;.5;.7)	.112893 .11291 .11293	.0844 .08441 .08441	.34057 .34059 .34061	.20311 20285 .20272	1.14782 1.14783 1.14785	1.7757 1.7759 1.776	.00065 .00326 .00457
f_I :(.1;.3;.5)	.112893 .15382 .20849	.0844 .16626 .2756	.34057 .47799 .61543	.20311 .20864 .21417	1.14782 1.04782 0.94782	1.7757 1.7494 1.723	.00065 .00092 .00118
d_I :(.1;.3;.5)	.112893 .12939 .1536	.0844 .09928 .12305	.34057 .41355 .53583	.20311 .20457 .20746	1.14782 1.14006 1.12964	1.7757 1.7471 1.7099	.00065 .00071 .00077
h_1 :(1;1.5;2)	.112893 .112894 .1129	.0844 .08439 .08439	.34057 .34057 .34057	.20311 .20313 .20314	1.14782 1.14782 1.14782	1.7757 1.7757 1.7757	.00065 .00044 .00033
α:(.1;.2;.3)	.112893 .11271 .11254	.0844 .08509 .08578	.34057 .34196 .34335	.20311 .20673 .21079	1.14782 1.14883 1.14984	1.7757 1.7760 1.7763	.00065 .00065 .00066
γ:(.1;.2;.3)	.112893 .11289 .11288	.0844 .0844 .0844	.34057 .34057 .34057	.20311 .20305 .20298	1.14782 1.14782 1.14782	1.7757 1.7757 1.7757	.00065 .00065 .00065
Δ:(.05;.15;.35)	.112893 .13252 .17185	.0844 .08579 .0886	.34057 .34336 .34899	.20311 .20336 .20383	1.14782 1.14985 1.15395	1.7757 1.7764 1.7779	.00065 .00263 .00668

$\Delta = p_3 - p_1 - \epsilon$

Table 3: Equilibrium Performance without SDGs

	$\mathit{\Pi}_{L1}^{M}$	Π_{L1}^{S}	q_{L1}	r_{L1}	w_{L1}	$p_{2,L1}$	I_{L1}
$\forall\ c_2,\ e,\ f_I,\ d_I,\ h_1,\ \gamma:$	.09225 .09225 .09225	.0505 .0505 .0505	.25125 .25125 .25125	.2002 .2002 .2002	1.201 1.201 1.201	1.8003 1.8003 1.8003	0 0 0
α:(.1; .2; .3)	.09225 .09202 .09179	.0505 .0510 .0515	.25125 .2525 .25375	.2002 .2008 .2018	1.201 1.202 1.203	1.8003 1.8005 1.8008	0 0 0
Δ:(.05; .15; .35)	.09225 .11179 .15096	.0505 .0515 .0536	.25125 .25375 .25875	.2002 .2006 .2014	1.201 1.203 1.207	1.8003 1.8008 1.8018	0 0 0

$\Delta = p_3 - p_1 - \epsilon$

Table 4: The Impact of SDGs on Outcomes

	$\mathit{\Pi}_{P1}^{M} - \mathit{\Pi}_{L1}^{M}$	$\Pi_{P1}^{S} - \Pi_{L1}^{S}$	$q_{P1} - q_{L1}$	$r_{P1} - r_{L1}$	$w_{P1} - w_{L1}$	$p_{2,P1} - p_{2,L1}$	$I_{P1} - I_{L1}$
c_2	+	+	+	+	-	-	+
e	+	+	+	+	-	-	+
f_I	+	+	+	+	-	-	+
d_I	+	+	+	+	-	-	+
h_1	+	+	+	+	-	-	+
α	+	+	+	+	-	-	+
γ	+	+	+	+	-	-	+
$p_3 - p_1 - \epsilon$	+	+	+	+	-	-	+

Table 5: Sensitivity Analysis

	$\partial(\mathit{\Pi}_{P1}^{M} - \mathit{\Pi}_{L1}^{M})$	$\partial(\Pi_{P1}^{S} - \Pi_{L1}^{S})$	$\partial(q_{P1} - q_{L1})$	$\partial(r_{P1} - r_{L1})$	$\partial(w_{P1} - w_{L1})$	$\partial(p_{2,P1} - p_{2,L1})$	$\partial(I_{P1} - I_{L1})$
∂c_2	> 0	> 0	> 0	< 0	> 0	> 0	> 0
∂e	> 0	> 0	> 0	< 0	> 0	> 0	> 0
∂f_I	> 0	> 0	> 0	> 0	$= 0$	< 0	> 0
∂d_I	> 0	> 0	> 0	> 0	< 0	< 0	> 0
∂h_1	> 0	< 0	< 0	> 0	< 0	< 0	< 0
$\partial \alpha$	> 0	> 0	> 0	> 0	> 0	> 0	> 0
$\partial \gamma$	< 0	$= 0$	$= 0$	< 0	$= 0$	$= 0$	$= 0$
$\partial(p_3 - p_1 - \epsilon)$	> 0	> 0	> 0	< 0	> 0	> 0	> 0