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Coordinating corporate social responsibility in a two-level supply chain under bilateral information asymmetry

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ABSTRACT

In this research, we study the problem of coordinating corporate social responsibility (CSR), an extremely important issue of supply chains in practice and academia, in a dyadic supply chain when a supplier and a manufacturer, two independent entities, commit CSR activities while both possess private CSR cost information i.e., bilateral information asymmetry. Decision structures and profits under information symmetry, information asymmetry-misreporting and asymmetry-estimation are modelled and investigated for each actor and the supply chain. The results show that in both information asymmetry scenarios, the supply chain profit decreases with respect to information symmetry, except for the exact estimate of the unknown cost. Hence, to deal with this inefficiency, we propose a coordination mechanism based on leader-leader Stackelberg models, rooted in the economic game. Finally, the numerical examples conducted in this paper seek to compare the results between the different decision models considered. The proposed coordination mechanism shows an improvement in global supply chain profit. Therefore, the main contribution of this study is to analyze the decisions under bilateral information asymmetry, rather than complete information or unilateral information asymmetry, where both actors are involved in CSR, rather than one or none and proposing appropriate coordinating mechanism. The proposed approach can be used by independent companies to coordinate their CSR efforts.

1. Introduction

Corporate Social Responsibility (CSR) represents companies' policies and practices, regarding social and environmental issues, which have impact on their shareholders and customers and also on their sustainability and corporate reputation (Jain and Winner, 2016). Over the last few decades, CSR has become a central issue of many consumers, companies and academia (Awan et al., 2019; Cai and Choi, 2020). Key findings of CSR study by Cone Communication 2017, state that 91% of consumers expect companies to adopt responsible practices with regard to social and environmental issues, 84% of them want to shop responsible products whenever possible and furthermore, 90% of them would boycott the irresponsible companies. Cox, T. A. (2019) finds that almost 70% of consumers say environmentally friendly and socially responsible practices are among the most important attributes of a company compared to price (44%). Many companies have seen this pressure and consider it in their operations by taking actions toward these types of responsibilities. According to Crook (2005), 85% of executives and investors consider CSR an essential element in investment decisions. Companies use different tools to respond to this pressure such as the introduction of "Codes of Conduct" and "CSR & Sustainability Reports" to ensure that they operate responsibly. However, most of these reports are single information transmission and the application of the two aforementioned responses becomes even more complicated in case of considering CSR in supply chain area rather than individual firm (Jorgensen et al., 2003). In addition, there exists the lack of sufficient qualitative or quantitative analysis supported by decision making indicators.

Nowadays due to globalization many companies are connected to each other through their supply chains and these companies, facing to pressures from customers and stakeholders, try to commit CSR efforts. For example, internationally known companies like adidas, Nike, Apple, Nestle, Walmart, etc. provide reports regarding their responsibilities and the way they lead their supply chain actors to behave more responsibly in global supply chains. Hence, recently some researchers have expanded their views of CSR from individual firm to supply chain

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perspective consisting of different directions such as qualitative (Gallear et al., 2012), empirical (Quintana-García et al., 2021), quantitative and mathematical modeling (Chan et al., 2020). An overlooked but important research direction is analytical models in coordinating supply chains where actors are involved in CSR (Loivet et al., 2020).

Lactalis, a leader in the collection and supply of milk, and Danone, a leader in the production of dairy products, are two major international players based in France in diary supply chain where both are involved in CSR activities, as shown by several CSR reports they announce. Through their announcements, they show the main CSR criteria and how they get involved using indicators such as environmental, social, societal and economic. Looking at the reports of these two companies, besides the economic indicator such as the presence as a market leader, we see that regarding environmental issues, they are taking measures for energy and waste management, for the reduction of the footprint as well as for the treatment and consumption of water. They also specify social and societal indicators such as employee well-being, diversity and equal opportunities, animal welfare, food safety, etc. These two independent companies make these efforts either voluntarily or in order to comply with the rules set by the authorities which come at cost in both cases. It could be their policy to share or not this cost information which affect several decisions and consequently affect their performance and that of the supply chain. Our problem is specifically motivated by this example where two supply chain actors put efforts in CSR and have private information. Although a large number of organizations in different supply chains commit CSR efforts through different means such as codes of conducts or standards set by governments to enhance their profit, the impact of these efforts on their profit and on supply chain, especially in decentralized supply chains (Zoghlami et al., 2016; Tliche et al., 2019) under information asymmetry with independent actors is still less explored. This gap in the literature is emphasized by two recent literature review studies Shen et al., (2019) and Vosooghidizaji et al., (2020).

To mitigate the effect of information asymmetry in supply chains, the literature shows that by using structured mechanisms such as contracts, supply chain actors can induce their adversaries to reveal private information. But most existing supply chain studies consider unilateral information asymmetry with one informed and one uninformed actor and adopt the principal-agent framework in which the principal has the dominant power to dictate contract terms, while the agent plays a rather passive role, either accepting the principal, or by withdrawing from the transaction (Feng et al., 2015). While Liu et al., 2019 consider the unilateral information asymmetry with a dominant leader (retailer) and a follower (supplier), we consider bilateral information asymmetry where there is no leader or follower in the supply chain. This is because, in general, neither side can control the entire supply chain, especially when two parties both have information advantages.

We examine a dyadic supply chain setting, consisting of an upstream supply chain actor (supplier, s) and a downstream supply chain actor (manufacturer, m) where both actors commit CSR efforts and deliver a responsible product to the final customer. CSR may consist of several commitments related to environmental such as investment in fuel-efficient technologies in logistics operations (Anser et al., 2020), social and societal issues and may cover a wide range of issues such as human rights, corruption, transfer pricing, taxation and biodiversity and humanitarian obligations, which comes at cost. However, supply chain actors do not control over each other's operations directly and may not have the actual information of CSR efforts and cost of these efforts while this information affect their relationships and supply chain performance. More concretely, we aim to analyze the impact of CSR cost on each actor and the global performance in decentralized supply chains under bilateral asymmetric information. Our analysis focuses on how CSR effort and CSR cost information affects financially the performances rather than how or which aspects of CSR are carried out by the actors.

This study contributes to the existing literature on supply chain coordination and CSR by incorporating the effects of involvement in CSR and information asymmetry on performance of the supply chain and that of actors, more precisely when both actors are involved in CSR, and both might have private information i.e., bilateral information asymmetry. Supply chain performance is analyzed under different information sharing scenarios, including when private information is shared, misreported, or estimated. Another important contribution of this study is that it proposes a coordination mechanism based on the AGV (d'Aspremont and Gérard-Varet, 1979) which makes it possible to reach situations where the actors are all winners, contrary to the principal-agent model which generally leads to a win-lose condition.

The reminder of this paper is as follows. In Section 2, we review related literature, including corporate social responsibility and information asymmetry in the supply chain. Section 3 formalizes the models, including the base model and different information scenarios. The first scenario is where information is symmetric and the second and third scenarios deal with situations where private information is either misreported or estimated. The last scenario is the AGV-based coordination scenario leading to a win-win situation. In section 4, we conduct the numerical experimentations. Finally, we present the concluding remarks in section 5.

2. Related literature

In this section, first we review the related literature on corporate social responsibility in supply chains and subsequently we review the information asymmetry in supply chains.

2.1. Corporate social responsibility in supply chain

European Commission defines CSR as "the responsibility of enterprises for their impacts on society and a process to integrate social, environmental, ethical, human rights and consumer concerns into their business operations and core strategy in close collaboration with their stakeholders". Despite the importance of CSR in supply chains, research in this area has remained vastly unexplored (Tang, 2018). Modak et al. (2020), state that it is a new emerging topic which received attention from 2000 and has evolved more since 2016. To define CSR from a supply chain perspective, Maloni and Brown (2006) state that, it not only has near the same meaning as business ethics, but also includes other dimensions such as philanthropy, community, diversity in the workplace, safety, human rights and the environment. Yadlapalli et al., (2020) propose an ontological framework of CSR with dimensions and discuss the CSR definitions in supply chains based on proposed framework. They also state that some scholars have referred to definitions from general CSR literature and some referred to definitions proposed by international organizations such as European Commissions, World bank, OECS, etc.

Despite the impact of CSR commitment or investment on the performance of each member and the global supply chains, the reviewed literature shows a research gap concerning analytical modeling of CSR in supply chains (Loivet et al., 2020). Ni and Li (2012), propose CSR as a product differentiation device by analyzing how actors' behaviors in committing CSR activities may lead to win-win situation through mutual incentive. To coordinate a dyadic supply chain with CSR commitment, Goering (2012), examines the efficiency of a two-part tariff contract where both actors, not simultaneously, apply CSR in their operations. Hsueh (2014), studies a model dealing with seasonal perishable goods with two actors where manufacturer commits CSR efforts, and a revenue sharing is proposed as coordinating mechanism. In a two-level closed-loop supply chain Panda et al. (2017), analyze CSR efforts though recycling and the effort is analyzed in the form of consumer surplus. In a similar supply chain setting, Nematollahi et al. (2017), examine the impact of CSR through two investment modes: CSR per unit of product and fixed investment. Giri et al., (2018), analyze a dyadic supply chain with the objective of producing and delivering responsible product. Demand in their model is a function of price, warranty period and greening level applied by manufacturer. To model the responsible efforts of both actors in a two-echelon supply chain, Raj et al. (2018), consider an actor committing CSR efforts and the other greening efforts where both influence demand positively. To analyze a concrete example of CSR, Modak et al., (2019), examine a closed loop supply chain by considering social work donation as CSR strategy committed by manufacturer which can positively influence the demand.

The above-mentioned studies consider CSR activities in their model and propose mechanisms such as two-part tariff and revenue sharing contracts to coordinate the supply chains and the main difference is the type of CSR and the number of actors involved in CSR activities. Nevertheless, in their analysis they do not consider that, in a real supply chain, the actors are independent with asymmetric information. In addition to considering exogenous effect of CSR on demand, Ma et al., (2017), examine information asymmetry where the downstream actor lacks full information about the upstream actor's CSR costs. Liu et al. (2019), model the information asymmetry in a two-stage setting consisting of a retailer and a supplier investing in CSR who may exaggerate CSR costs when informing the retailer i.e., one actor with informational advantage. A compensation fund is proposed as coordination mechanism.

Unlike the above literature, we consider a setting where both independent actors commit CSR and both can have private information on the cost related to their efforts i.e., bilateral information asymmetry. In identifying the barriers to social sustainability initiatives, a key dimension identified by Awan et al. (2020) is lack of shared understanding and exchange of information which shows the role of information asymmetry. Table 1 summarizes the differences between our model and the existing literature. Hence, in next subsection we discuss information asymmetry.

2.2. Information asymmetry in supply chain

One of the complex realities facing supply chains is the asymmetry of information which, through its various facets, complicates interactions between members. It is well known that supply chain performance is negatively affected by information asymmetry, which can relate to cost, demand, supply, etc. According to Kostamis and Duenyas (2011), "*very few, if any, supply chains can function with all their members possessing the same amount of information*". One way to discuss information asymmetry categories in supply chains is based on the number of actors which includes: unilateral, bilateral, and multilateral information asymmetry. In the unilateral case, only one member has superior knowledge of an element affecting decisions. In the bilateral information asymmetry, both actors have different information levels that can be about the same element or different elements and if there are more than two actors, each with asymmetric information, multilateral information asymmetry exists. By considering the fact that, in the supply chain context, there is still no taxonomy of asymmetric information, Vosooghidizaji et al. (2020) analyze the information asymmetry based on nature of information. Beyond analyzing two typical information types i.e., cost and demand information, they discuss Capacity information asymmetry, Quality information asymmetry, Disruption information asymmetry, Attribute information asymmetry, Inventory information asymmetry, Price information asymmetry, Effort level information asymmetry and Objective function information asymmetry. Beside classifying the information asymmetry, they explain how this piece of information is considered through different models i.e., how the actors cope with it which includes: Information Sharing, Assessment by probability (discrete), Assessment by probability (continuous), Estimation and No disclosure of information (local information).

Table 1
This paper in comparison with the literature.

Author	CSR		Information Asymmetry
	Upstream actor	Downstream actor	
Hsueh (2014); Panda et al., (2017) Nematollahi et al., (2017); Giri et al. (2018); Modak et 2019	✓	×	Not considered
Goering (2012) [a]	✓	×	Not considered
	×	✓	
Raj et al. (2018); Ni and Li (2012)	✓	✓	Not considered
Liu et al. (2019)	✓	×	Unilateral
Ma et al. (2017)	✓	✓	Unilateral
This paper	✓	✓	Bilateral

[a] Goering (2012) considers a scenario where only upstream actor is involved in CSR activities and he considers another scenario in which only downstream actor is involved in CSR activities. In other words, he does not analyze a scenario considering both actors involved in CSR activities.

To deal with the information asymmetry, scholars proposed several scenarios and mechanisms such as wholesale price contract, two-part tariff contracts, quantity discounts, etc. to ensure coordination among the supply chain actors. In modelling supply chain coordination problems under information asymmetry, dyadic structure has been widely used and one of the pioneering works is Corbett and De Groote (2000) which is based on principal-agent model. Similarly, Zhang and Chen (2013) study a supplier-retailer supply chain under demand information asymmetry and show that revenue sharing can coordinate the supply chain. Zissis et al. (2015) analyze a supply chain composed of a manufacturer and a retailer where the buyer has private holding cost information. To coordinate the supply chain, they suggest a quantity discounts contract which reduces the cost for both actors. Shen et al., (2019) state that sharing contracts, such as profit or revenue sharing, can lead to better supply chain performance than other contracts as it encourages parties to engage in coordination and information sharing.

A common assumption in majority of studies in coordinating supply chains is that one of the actors act as leader (principal) by having information advantage and the other actor act as follower (agent). Therefore, the interaction is analyzed in the form of leader-follower or principal-agent which can potentially lead to win-lose situation. However, applying leader-follower game where both actors have information advantage is not applicable. Looking at CSR studies in supply chain context not considering information asymmetry and very few considering unilateral information asymmetry (Ma et al., 2017; Liu et al., 2019) that may not represent real supply chains, analyzing bilateral information asymmetry among members can provide a more realistic picture of supply chain. Therefore, the main contribution of this study is to analyze a dyadic supply chain where both actors are involved in CSR efforts and both have an informational advantage, as shown in Table 1, and to propose a coordination mechanism through leader-leader game.

3. Model

We consider a dyadic supply chain consisting of an upstream actor, supplier (s) and a downstream actor, manufacture (m). A leader-leader Stackelberg situation in which both actors apply CSR efforts which can positively affect the demand. It is assumed that demand is a function of product price and CSR efforts of both actors. In other words, demand increases with CSR efforts and decreases with product price as stated in Eq. (1).

$$D = a - bP + \alpha_s e_s + \alpha_m e_m \quad \text{Eq. (1)}$$

In Eq. (1), D is the final demand, a is base market size, b stands for price influence on demand. e_s and e_m are the corporate social efforts of supplier and manufacturer, respectively. The parameter α_s is supplier's CSR effort (e_s) impact on demand, α_m stands for manufacturer's CSR effort (e_m) impact on demand. The terms $\alpha_m e_m$ and $\alpha_s e_s$ state increased demand of product due to the manufacture's and supplier's corporate social responsibility, respectively. The deterministic demand and linear function assumption is commonly adopted in the operations research literature and helps to better understand complex problems (Savaskan et al., 2004; Huang and Wang, 2018). Table 2 summarizes the notations used in this paper.

To calculate the profits of each actor, π_s and π_m , wholesale price (W), supplier's production cost (C), retail price (P) and demand (D) have been used as in Eq (2) and (3). For calculating the CSR effort costs, we consider a quadratic convex function, a common assumption to show marginal cost increase (Ma et al., 2017; Biswas et al., 2018; Choi et al., 2018). k_m and k_s are the CSR effort costs of manufacturer and supplier, respectively. $\frac{1}{2}\ k_s e_s^2$ and $\frac{1}{2}\ k_m e_m^2$ are the functions of CSR effort costs of manufacturer and supplier. Since the CSR effort (e_m and e_s) and CSR cost (k_m and k_s) are positive they are increasing graphs. As Liu et al., 2019 state, the non-linear cost assumption represents the diminishing rate of return to corporate social responsibility commitment. If the supplier's unit production cost is C and W is the wholesale price, the profit functions of supplier and manufacturer can be expressed as follows:

$$\pi_s = (W - C)(a - bP + \alpha_s e_s + \alpha_m e_m) - \frac{1}{2}\ k_s e_s^2 \qquad \text{Eq. (2)}$$

$$\pi_m = (P - W)(a - bP + \alpha_s e_s + \alpha_m e_m\ ) - \frac{1}{2}\ k_m e_m^2 \qquad \text{Eq. (3)}$$

In next sections we present decision making models under symmetric and asymmetric information.

3.1. Decision models under information symmetry

The optimal decisions of actors under information symmetry are calculated in this section. In symmetry model, supplier as the first mover sets its profit maximizing wholesale price and CSR effort, e_s. Based on supplier's decisions, manufacturer decides about the product price and CSR efforts, e_m. To find the solution, we consider the manufacturer's best response functions with respect to the value of W and e_s. Manufacturer's decisions are expressed through following proposition.

Proposition 1. *Under information symmetry with a supplier and a manufacturer both committing CSR efforts, there exists an optimal solution with unique values of P and e_m which maximizes manufacturer's profit as follows*:

$$P(e_s, W) = \frac{k_m(a + \alpha_s e_s + bW) - \alpha_m^2 W}{2bk_m - \alpha_m^2} \qquad \text{Eq. (4)}$$

$$e_m(e_s, W) = \frac{\alpha_m(a + \alpha_s e_s - bW)}{2bk_m - \alpha_m^2} \qquad \text{Eq. (5)}$$

Proof. In equation (3) *we set* $\frac{\partial \pi_m}{\partial P} = 0$ *and* $\frac{\partial \pi_m}{\partial e_m} = 0$ *and solving simultaneously for P and e_m provides* Eq. (4) *and* Eq. (5).

In order to analyze supplier's decisions which maximizes the profit, we use the Eq. (1). *Supplier's decision is expressed by following proposition.*

Proposition 2. *In a two-level supply chain with a supplier and a manufacturer both committing CSR efforts, there exists an optimal solution under information symmetry with unique values which maximizes supplier's profit as follow*:

$$W^* = \frac{(a - bc)\left(2k_m k_s b - k_s\alpha_m^2\right)}{b\left(4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2\right)} + c \qquad \text{Eq. (6)}$$

$$e_s^* = \frac{(a - bc)(k_m\alpha_s)}{4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2} \qquad \text{Eq. (7)}$$

Proof. First, Eq. (4) *and* Eq. (5) *are substituted in* Eq. (2). *Then the partial derivatives* $\frac{\partial \pi_s}{\partial e_s}$ *and* $\frac{\partial \pi_s}{\partial W}$ *are set equal to zero and solving simultaneously for W and e_s provides* Eq. (6) *and* Eq. (7).

To calculate optimal price and optimal effort values of the manufacturer, P^* and e_m^*, we replace Eq. (6) *and* Eq. (7) *in* Eq. (4) *and* Eq. (5) *which provides*:

$$P^* = \frac{(a - bc)(k_m k_s)}{4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2} + \frac{(a - bc)\left(2k_m k_s b - k_s\alpha_m^2\right)}{b\left(4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2\right)} + c \qquad \text{Eq. (8)}$$

$$e_m^* = \frac{(a - bc)(k_s\alpha_m)}{4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2} \qquad \text{Eq. (9)}$$

In order to obtain the optimal profit values of supplier and manufacturer, we substitute Eq. (6), Eq. (7), Eq. (8), *and* Eq. (9) *in* Eq. (2) *and* Eq. (3) *which provides*:

$$\pi_s^* = \frac{(a - bc)^2(k_m k_s)}{2\left(4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2\right)} \qquad \text{Eq. (10)}$$

$$\pi_m^* = \frac{(a - bc)^2\left(k_m k_s^2\right)\left(2k_m - \alpha_m^2\right)}{2\left(4k_m k_s b - k_m\alpha_s^2 - 2k_s\alpha_m^2\right)^2} \qquad \text{Eq. (11)}$$

3.2. Decision models under bilateral information asymmetry

In this section, we analyze the decision models when CSR costs are the private information of actors. The supplier decides on wholesale price and CSR efforts which depend on CSR effort costs of both actors, k_s and k_m. To analyze how information asymmetry affects decisions, we examine two scenarios: decisions based on announced CSR costs (misreporting) and based on estimated CSR costs (estimation).

3.2.1. Information asymmetry-misreporting

We assume that supplier announces CSR costs as $\widehat{k}_s$ while the real cost is k_s, $(\widehat{k}_s \geq k_s)$, and the manufacturer announces $\widehat{k}_m$, while the real cost is k_m, $(\widehat{k}_m \geq k_m)$. The reason behind that we do not consider $(\widehat{k}_s < k_s)$ and $(\widehat{k}_m < k_m)$, is that the logic actor does not understate the costs. When actors pretend to be $\widehat{k}_s$ and $\widehat{k}_m$, their profit function becomes:

$$\pi_s\left(\widehat{k}_s|k_s\right)_{\widehat{k}_m} = [(W - C)(a - bP + \alpha_s e_s + \alpha_m e_m)]_{\widehat{k}_s,\widehat{k}_m} - \frac{1}{2}\ k_s\left(e_s^2\right)_{\widehat{k}_s,\widehat{k}_m} \qquad \text{Eq. (12)}$$

$$\pi_m\left(\widehat{k}_m|k_m\right)_{\widehat{k}_s} = [(P - W)(a - bP + \alpha_s e_s + \alpha_m e_m)]_{\widehat{k}_s,\widehat{k}_m} - \frac{1}{2}\ k_m\left(e_m^2\right)_{\widehat{k}_s,\widehat{k}_m} \qquad \text{Eq. (13)}$$

To analyze actors' decisions under information asymmetry-misreporting (exaggeration), propositions 3 and 4 are proposed:

Proposition 3. *In a two-level supply chain with a supplier and a manufacturer both committing CSR efforts, under bilateral information asymmetry both exaggerating their effort cost, there exists an optimal solution with unique values which maximizes manufacturer's profit as follow*:

Table 2
Notations.

a	Base market size
b	Price sensitive parameter
P	Retail price
W	Wholesale price
C	Supplier's (production) cost
D	Demand
α_s	Supplier's CSR effort impact on demand
α_m	Manufacturer's CSR effort impact on demand
e_s	Supplier's CSR effort
e_m	manufacturer's CSR effort
k_s	Supplier's CSR effort cost
k_m	Manufacturer's CSR effort cost
π_s	Supplier's profit
π_m	Manufacturer's profit
γ	Allocation ratio

$$\widehat{P}^* = \frac{(a-bc)(\widehat{k}_m \widehat{k}_s)}{4\widehat{k}_m\widehat{k}_s b - \widehat{k}_m\alpha_s^2 - 2\widehat{k}_s\alpha_m^2} + \widehat{W}^* \qquad \text{Eq. (14)}$$

$$\widehat{e}_m^* = \frac{(a-bc)(\widehat{k}_s\alpha_m)}{4\widehat{k}_m\widehat{k}_s b - \widehat{k}_m\alpha_s^2 - 2\widehat{k}_s\alpha_m^2} \qquad \text{Eq. (15)}$$

Proposition 4. *In a two-level supply chain with a supplier and a manufacturer both committing CSR efforts, under bilateral information asymmetry both exaggerating their effort cost, there exists an optimal solution with unique values which maximizes supplier's profit as follow:*

$$\widehat{W}^* = \frac{(a-bc)\left(2\widehat{k}_m\widehat{k}_s b - \widehat{k}_s\alpha_m^2\right)}{b\left(4\widehat{k}_m\widehat{k}_s b - \widehat{k}_m\alpha_s^2 - 2\widehat{k}_s\alpha_m^2\right)} \qquad \text{Eq. (16)}$$

$$\widehat{e}_s^* = \frac{(a-bc)(\widehat{k}_m\alpha_s)}{4\widehat{k}_m\widehat{k}_s b - \widehat{k}_m\alpha_s^2 - 2\widehat{k}_s\alpha_m^2} \qquad \text{Eq. (17)}$$

Proof of proposition 3 *and* 4. *See* proposition 1 *and* 2.

In order to obtain the optimal profit values of supplier and manufacturer, we substitute Eq. (14), Eq. (15), Eq. (16) *and* Eq. (17) *in* Eq. (12) *and* Eq. (13) *which provide*:

$$\widehat{\pi}_s^* = \frac{(a-bc)^2(\widehat{k}_m\widehat{k}_s)}{2\left(4\widehat{k}_m\widehat{k}_s b - \widehat{k}_m\alpha_s^2 - 2\widehat{k}_s\alpha_m^2\right)} + \frac{(\widehat{k}_s - k_s)\widehat{e}_s^{*2}}{2} \qquad \text{Eq. (18)}$$

$$\widehat{\pi}_m^* = \frac{(a-bc)^2\left(\widehat{k}_m\widehat{k}_s^2\right)\left(2\widehat{k}_m - \alpha_m^2\right)}{2\left(4\widehat{k}_m\widehat{k}_s b - \widehat{k}_m\alpha_s^2 - 2\widehat{k}_s\alpha_m^2\right)^2} + \frac{(\widehat{k}_m - k_m)\widehat{e}_m^{*2}}{2} \qquad \text{Eq. (19)}$$

In Eq. (18) *and* Eq. (19) *second phrases at the right-hand side indicate the effects of considering real costs in calculating their own profit while actors are pretending higher costs.*

3.2.2. Information asymmetry-estimation

In this case, CSR effort costs are private information of actors and neither of them announce it. We examine decision structures when actors estimate the value of unknown information i.e., supplier estimates CSR effort cost of manufacturer as $\widetilde{k}_m$ while the real cost is k_m and the manufacturer estimates the CSR effort cost of supplier as $\widetilde{k}_s$ while the real cost is k_s.

Recall from symmetric case, supplier's decisions in setting profit maximizing wholesale price W and effort level e_s, are based on the manufacturer reactions which depend on k_m and is not known by supplier. By replacing the estimated value of the cost, $\widetilde{k}_m$, in Eq. (4) and Eq. (5), manufacturer's reaction will be:

$$P = \frac{\widetilde{k}_m(a + \alpha_s e_s + bW) - \alpha_m^2 W}{2b\widetilde{k}_m - \alpha_m^2} \qquad \text{Eq. (20)}$$

$$e_m = \frac{\alpha_m(a + \alpha_s e_s - bW)}{2b\widetilde{k}_m - \alpha_m^2} \qquad \text{Eq. (21)}$$

By substituting manufacturer's reaction in Eq. (2), supplier's profit can be obtained. From new profit function, optimal wholesale price and effort level can be obtained as follows:

$$W^* = \frac{(a-bc)\left(2\widetilde{k}_m k_s b - k_s\alpha_m^2\right)}{b\left(4\widetilde{k}_m k_s b - \widetilde{k}_m\alpha_s^2 - 2k_s\alpha_m^2\right)} + c \qquad \text{Eq. (22)}$$

$$e_s^* = \frac{(a-bc)(\widetilde{k}_m\alpha_s)}{4\widetilde{k}_m k_s b - \widetilde{k}_m\alpha_s^2 - 2k_s\alpha_m^2} \qquad \text{Eq. (23)}$$

After deciding on W and e_s, supplier proposes the decision to manufacturer and then manufacturer decides about maximizing P and e_m.

The terms W^* and e_s^*, instead of W and e_s , and real effort cost of manufacturer, k_m , are replaced in Eq. (20) and Eq. (21):

$$P = \frac{k_m\left(a + \alpha_s e_s^* + bW\right) - \alpha_m^2 W^*}{2bk_m - \alpha_m^2} \qquad \text{Eq. (24)}$$

$$e_m = \frac{\alpha_m\left(a + \alpha_s e_s^* - bW^*\right)}{2bk_m - \alpha_m^2} \qquad \text{Eq. (25)}$$

Calculated P and e_m in Eq. (20)-Eq. (21) and Eq. (24)- Eq. (25) are the same if and only if $\widetilde{k}_m = k_m$.

If it is unilateral information asymmetry and manufacturer had full information of supplier's effort cost, decisions could be made by proposed W^* and e_s^*, but manufacturer lacks the information about k_s. In addition to considering k_m and the proposed W^* and e_s^* in manufacturer's decision making, in order to evaluate the proposed W and e_s and the corresponding profit from manufacturer perspective, supplier's decisions are analyzed based on estimated effort cost $\widetilde{k}_s$. In other words, expected profit of manufacturer is calculated while k_s is not known.

$$P^* = \frac{(a-bc)(k_m\widetilde{k}_s)}{4k_m\widetilde{k}_s b - k_m\alpha_s^2 - 2\widetilde{k}_s\alpha_m^2} + \frac{(a-bc)\left(2k_m\widetilde{k}_s b - \widetilde{k}_s\alpha_m^2\right)}{b\left(4k_m\widetilde{k}_s b - k_m\alpha_s^2 - 2\widetilde{k}_s\alpha_m^2\right)} \qquad \text{Eq. (26)}$$

$$e_m^* = \frac{(a-bc)(\widetilde{k}_s\alpha_m)}{4k_m\widetilde{k}_s b - k_m\alpha_s^2 - 2\widetilde{k}_s\alpha_m^2} \qquad \text{Eq. (27)}$$

Next subsection depicts different equilibriums for each decision structure.

3.2.3. Equilibriums

Fig. 1 shows the equilibriums under different decision structures. True effort costs, k_m and k_s, are shown as point A. Second chart in the Fig. 1, shows where one or both actors may misreport the real costs as $\widehat{k}_m$ and $\widehat{k}_s$. For example, point C indicates the case where supplier reports $\widehat{k}_s$ while the real cost is k_s and manufacturer reports the real cost, k_m. The estimation scenarios are shown in the last graph in Fig. 1 in which an actor estimates the effort cost of the other one with a value higher, lower or equal to the real value. As an example, point E indicates the case when supplier estimates the effort cost of manufacturer with $\widetilde{k}_m 2$ while the real value is k_m.

3.2.4. Coordination mechanism

There is a widespread recognition that contracts using screening principle can achieve information sharing under unilateral information asymmetry condition. Nevertheless, in bilateral information asymmetry condition, where both actors have private information, it may not be applicable as, usually, there is no unique member possessing the full control of the supply chain. Hence, we propose a coordination mechanism to induce both actors to share information truthfully. We apply an incentive mechanism, first proposed by d'Aspremont and Gérard-Varet (1979), henceforth AGV. This mechanism which gives each member an incentive to share truthful information through transfer payment (Athey and Segal, 2013; d'Aspremont and Gérard-Varet, 1979). The transfer payment is equal to the expected externality imposed by an actor (e.g., supplier) to another actor (manufacturer) when misreporting. When supplier misreports, imposes $\Delta\pi_m$ externality to manufacturer, and manufacturer imposes $\Delta\pi_s$ to supplier by misreporting. Based on AGV mechanism, if supplier receives $\Delta\pi_m$ from manufacturer, will share truthfully k_s and if manufacturer receives $\Delta\pi_s$ from supplier will share k_s truthfully. In other words, each actor shares information truthfully in exchange for receiving a transfer payment.

Proposition 5. *The mechanism* $\{W, e_s, T_s, T_m, \gamma\}$, *where* $0 < \gamma < 1$, *can coordinate supply chain under bilateral information asymmetry by giving incentives to supplier and manufacturer to share their CSR cost information truthfully.*

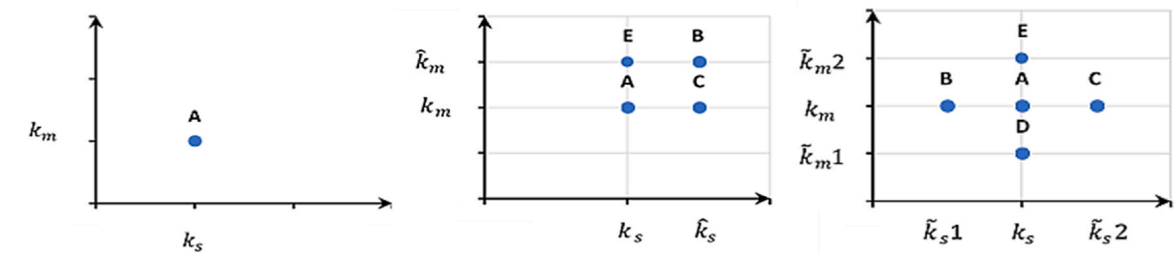

Fig. 1. Equilibriums regarding different effort costs.

Based on proposition 5, actors agree on transfer payments by allocation proportion ex ante profit which will let them to share the profit based on that.

To calculate the payment for each actor, when they announce their CSR effort costs truthfully i.e., $k_m = \widehat{k}_m$ and $k_s = \widehat{k}_s$, the following formulas should be satisfied:

$$E(\pi_s)_{k_s} \geq E(\widehat{\pi}_s)_{\widehat{k}_s} \quad \text{Eq. (28)}$$

$$E(\pi_m)_{k_m} \geq E(\widehat{\pi}_m)_{\widehat{k}_m} \quad \text{Eq. (29)}$$

Left hand side in Eq. (28) *and* Eq. (29) *are expected profit values when actors share truthfully their information that should be equal or greater than the right side which shows the expected profits when they misreport their cost information. By indicating the transfer payments with T_s and T_m we obtain:*

$$E(\pi_s) = E(\widehat{\pi}_s) + T_s \quad \text{Eq. (30)}$$

$$E(\pi_m) = E(\widehat{\pi}_m) + T_m \quad \text{Eq. (31)}$$

Using the AGV mechanism and the efficiency of sharing mechanisms in supply chain coordination, as mentioned in section 2, *we set the allocation rules in a way that the expected externalities are a share of their profit:*

$$T_s = \gamma[E(\widehat{\pi}_m)] - (1-\gamma)E(\widehat{\pi}_s) \quad \text{Eq. (32)}$$

$$T_m = (1-\gamma)E(\widehat{\pi}_s) - \gamma[E(\widehat{\pi}_m)] \quad \text{Eq. (33)}$$

By replacing the transfer payments in profit functions, we obtain the ex-ante profit functions:

$$E(\pi_s) = E(\widehat{\pi}_s) + \gamma[E(\widehat{\pi}_m)] - (1-\gamma)E(\widehat{\pi}_s) = \gamma[E(\widehat{\pi}_m) + E(\widehat{\pi}_s)] \quad \text{Eq. (34)}$$

$$E(\pi_m) = E(\widehat{\pi}_m) + (1-\gamma)E(\widehat{\pi}_s) - \gamma[E(\widehat{\pi}_m)] = (1-\gamma)[E(\widehat{\pi}_m) + E(\widehat{\pi}_s)] \quad \text{Eq. (35)}$$

While γ may be set by negotiation or bargaining power, we propose the allocation ratio γ, by using the whole supply chain profit and expected profit of each actor, as follows:

$$\gamma = \frac{E(\widehat{\pi}_s)}{E(\pi_{sc})} \quad \text{Eq. (36)}$$

$$(1-\gamma) = \frac{E(\widehat{\pi}_m)}{E(\pi_{sc})} \quad \text{Eq. (37)}$$

Therefore, the obtained allocation ratio is:

$$\gamma = \frac{4k_m k_s b - k_m \alpha_s^2 - 2k_s \alpha_m^2}{4k_m k_s b - k_m \alpha_s^2 - 2k_s \alpha_m^2 + k_s\left(2k_m - \alpha_m^2\right)} \quad \text{Eq. (38)}$$

Generally, allocating supply chain profit proportionally is an indication of negotiation power which may include expectations regarding minimum (expected) profit plus information advantage. In contrast to unilateral information asymmetry, under bilateral information asymmetry both have information advantage and none of the can control the whole supply chain and hence, the allocation rule by γ is acceptable for both. In this sense, both have incentive to integrate the whole supply chain decision and not to deviate from the real costs where $k_m = \widehat{k}_m = \widetilde{k}_m$ and $k_s = \widehat{k}_s = \widetilde{k}_s$ meaning point A in Fig. 1 *rather than any other point. In other words, it leads to a collaboration to improve the whole supply chain performance. The outcome of this mechanism can be compared with the hypothesis proposed by* Awan and Sroufe (2020), *where they state the significant relationship between collaboration and social improvement in analyzing the interorganizational relationship.*

4. Numerical example

In this section, we present the numerical examples to gain further insights by comparing decision scenarios and propositions investigated in previous sections. In choosing the values in numerical example, we have tried to use similar values applied in the literature (Table 1). We conduct the numerical examples, first, by choosing the following values: $a = 40$, $b = 1$, $\alpha_s = 1$, $\alpha_m = 1.5$, $C = 5$, $k_m = 1.5$ *and* $k_s = 1.5$. In this setup we vary k_m and k_s from 1.5 to 2.5 in order to analyze the effect of each actor effort cost changes on their performance and that of supply chain under different information scenario.

4.1. Information symmetry

In symmetric case when $k_m = 1.5$*and* $k_s = 1.5$, based on propositions 1 and 2, the following optimal values obtained: $W^* = 57.5$, $e_s^* = 70$, $P^* = 162.5, e_m^* = 105$, $\pi_s^* = 1837.5$ and $\pi_m^* = 2756.25$. Fig. 2 validates that any other value higher or lower than optimal effort level will result in decline of manufacturer's profit and similarly, as it is shown in Fig. 3, if any price is set rather than the optimal value will lead to a profit less than optimal.

The optimal points presented in Figs. 2 and 3 regarding effort level and price act as benchmark to evaluate the performance under information asymmetry scenarios and also efficiency of coordination scenario. It can be argued that increasing CSR effort is always good, but as it is evident from the Fig. 3 after the optimal effort level, it negatively affects the supply chain profit. This issue could be explained with the

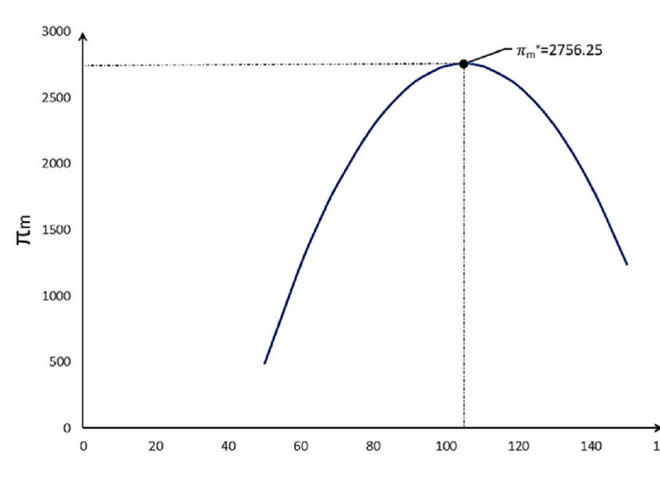

Fig. 2. The relationship between effort level and profit.

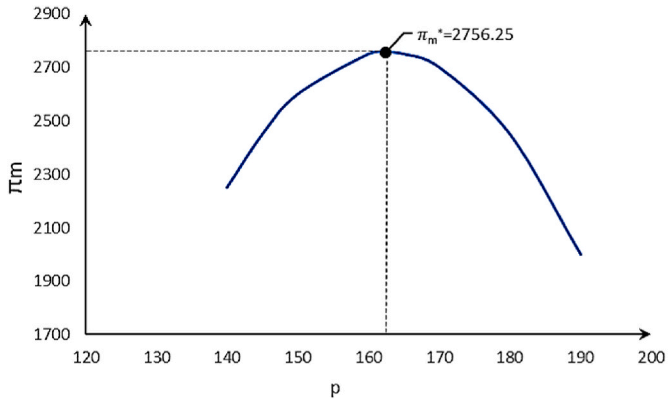

Fig. 3. The relationship between price and profit.

help of terms such as completely or hundred percent environmentally friendly or social product which can be a desire of a group of customers. This type of analysis requires different demand pattern where the price has a small role or no role.

The relationship between effort costs and effort levels are shown in Figs. 4 and 5, which illustrate that when the effort costs increase, the effort levels decline but differently. In Fig. 4, for a fixed k_s ($k_s = 1.5$), when k_m increases from 1.5 to 2.5, e_m decreases from 105 to 13.7 and e_s from 70 to 15.2. For a fixed $k_m = 1.5$, if k_s increases from 1.5 to 2.5, e_m declines from 105 to 58 and e_s from 70 to 23 (Fig. 5). The reason that the decline patterns are different is due to the coefficients $\alpha_s = 1$ and $\alpha_m = 1.5$, and it indicates that higher coefficient of α_m leads to more decline.

4.2. Information asymmetry-misreporting

To compare the information asymmetry-misreporting case with symmetric, we assume the parameters as: a = 40, b = 1, $\alpha_s = 1$, $\alpha_m = 1.5$, C = 5, $k_m = 1.6 and\ k_s = 1.5$. As stated in section 3, in symmetric case, when any of k_s or k_m, increases it will lead to decrease in profit of each actor and the whole supply chain. In case of asymmetric information-misreporting, when an actor exaggerates about effort cost, loses less than the other actor, in other words, the misreporting actor imposes more loss to other one. Fig. 6 shows how manufacturer's and supplier's profit are affected when the manufacturer exaggerates on effort cost i.e. when the real cost is $k_m = 1.6$, he reports $\widehat{k}_m = 1.6, 1.7, 1.8 and 1.9$. The optimal profits of both actors under symmetric scenario are depicted (two horizontal lines) when the real cost is 1.6. It provides the comparison of misreporting and symmetric cases which shows that manufacturer imposes more loss to supplier.

In order to see the effect of supplier's misreporting, we assume the same parameters. Fig. 7 shows how supplier imposes more loss on manufacturer by misreporting $\widehat{k}_s = 1.5, 1.6, 1.7, 1.8 and 1.9$ while the real. $k_s = 1.5$.

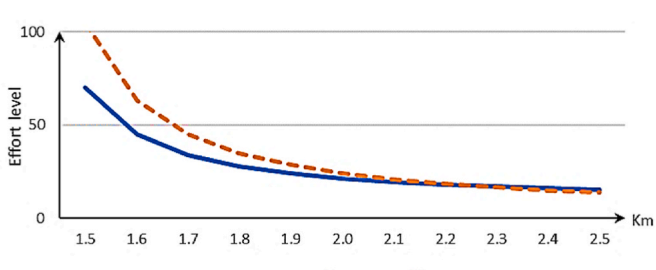

Fig. 4. Impact of km on efforts.

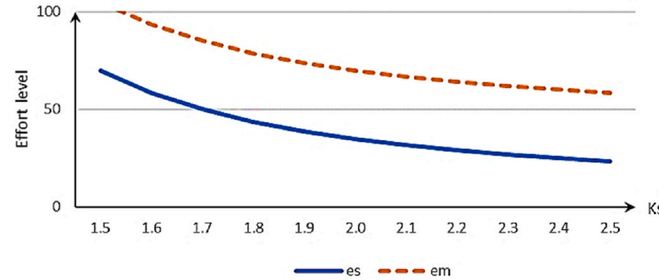

Fig. 5. Impact of ks on efforts.

4.3. Information asymmetry-estimation

As mentioned in section 3, when an actor estimates the unknown cost of the other actor, it may be estimated higher, equal, or smaller than the real cost. To conduct the estimation scenario, we consider three cases where the real costs (k_m , k_s) are: {A:(1.6, 1.5), B:(1.9, 1.8), C:(2.1, 2)}. Supplier, lacking the effort cost information of manufacturer, k_m, estimates it as $\widetilde{k}_m$ and makes decisions by ($\widetilde{k}_m$, k_s): {A:(1.9, 1.5), B:(1.9, 1.8), C:(1.9, 2)}. By assuming the same parameters, a = 40, b = 1, $\alpha_s = 1$, $\alpha_m = 1.5$, C = 5, supplier sets expected profit maximizing wholesale price and effort level as (W^*, e_s^*): {(34.6, 24,2), (31.5, 18), (30, 16)} and proposes to manufacturer. While supplier makes the decisions based on $\widetilde{k}_m$, manufacturer sets the effort level and price based on real cost, k_m , which affects the demand and consequently the real profit. Fig. 8 shows that supplier's profit status where $E(\pi_s)$ is expected profit, π_s^* is the optimal profit when costs are known and π_s is the real profit when manufacturer sets P and e_m. As it is shown in the Fig. 8 when supplier estimates a higher k_m ,($\widetilde{k}_m$ =1.9 > 1.6) i.e., point A, expected profit is lower than the optimal and real profit. When the exact value of k_m is estimated, ($\widetilde{k}_m$ =1.9) i.e., point B, expected, optimal and real profit are equal. Finally, if estimated k_m is lower than the real cost, ($\widetilde{k}_m$ =1.9 < 2.1) i.e., point C, supplier expects more than the optimal profit while the real profit is lower than optimal.

4.4. Coordination

As it was shown numerically, decisions under information asymmetry led to supply chain inefficiency with profit loss of the whole system and profit loss for the actors differently, depending on the actors misreporting or wrong estimation actions. To analyze the coordination mechanism, we assume the parameter values as: a = 40, b = 1, $\alpha_s = 1$, $\alpha_m = 1.5$, C = 5, $k_m = 1.9 and\ k_s = 1.8$. Supply chain profit under information asymmetry and coordination mechanism is calculated as: 1000,79. Depending on the ex-ante negotiation on γ, the profit will be allocated. Fig. 9 shows ex post profits with 33 negotiation scenarios.

As it is shown, the supply chain becomes as efficient as with information symmetry, but the actors' profits may vary. While in the symmetric case $\pi_s = 569, 23$ and $\pi_m = 431, 56$, in the coordination mechanism the profits can be: $542.3 \leq \pi_s \leq 602.5$, $398.3 \leq \pi_m \leq 455.5$.

4.5. Comparative analysis

In order to find out the effect of information asymmetry on each actor's performance and efficiency of proposed coordination mechanism, we examine the profits under different decisions by taking the parameter values as: a = 40, b = 1, = 1, $\alpha m = 1.5$, C = 5, $km = 1.9$ *and* $ks = 1.8$. Table 3 shows the profits of supplier and manufacturer under four decision scenarios. Under information symmetry the optimal profits of supplier and manufacturer are $\pi_s = 569{,}23$ and $\pi_m = 431{,}56$ indicating the whole supply chain profit as $\pi_{sc} = 1000.8$. In asymmetric-misreporting case when actors (even one actor) exaggerate their CSR

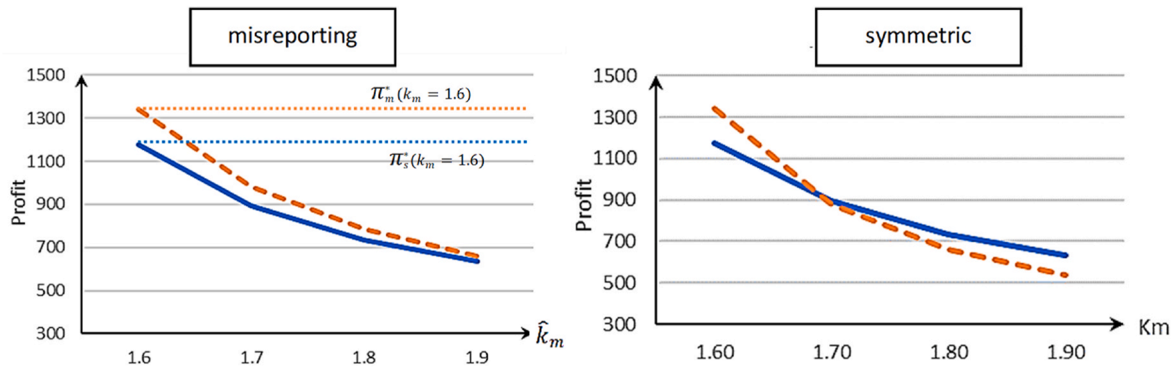

Fig. 6. Impact of misreporting manufacturer's effort cost on profits.

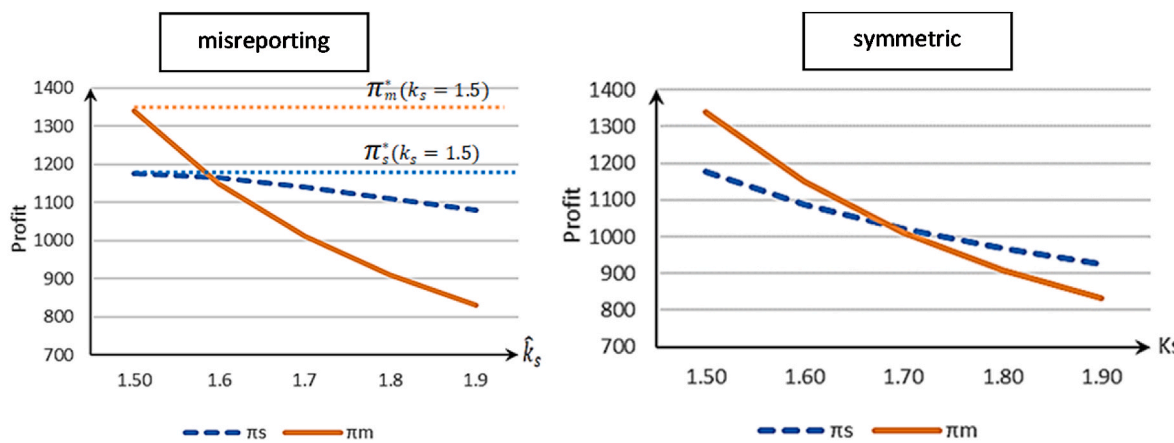

Fig. 7. Impact of misreporting supplier's effort cost on profits.

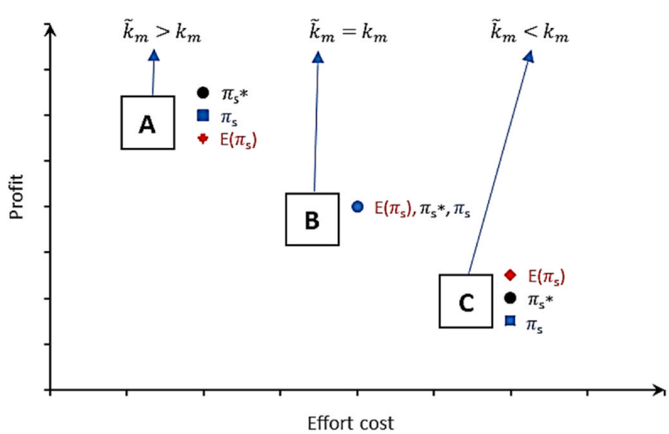

Fig. 8. Profit comparison under different effort cost estimations.

cost, the profits for supplier and manufacturer are lower than that of symmetric information case i.e., 433.37 $\leq \pi_s \leq$ 568.05 and 312.96 $\leq \pi_m \leq$ 409.02. For example, when supplier reports the cost as $\widehat{k}_s = 1.9$ instead of real cost $k_s = 1.8$ and manufacturer reports the cost as $\widehat{k}_m = 2$ instead of $k_m = 1.9$, leads to $\pi_s = 511.8$, $\pi_m = 380.9$ and $\pi_{sc} = 892.7$ which are lower in comparison with symmetric information decisions.

Looking at the asymmetric-estimation scenario, when the cost is estimated it leads to more possible variation in profits (372.46 $\leq \pi_s <$ 569.23 and 123.14 $\leq \pi_m <$ 662.79) depending on how big the estimated cost value is different from the real value. For instance, when the supplier estimates the manufacturer's cost as $\widetilde{k}_m = 1.95$ instead of $k_m = 1.9$, it will lead to profits $\pi_s = 538.8$, $\pi_m = 379.4$ and $\pi_{sc} = 918.2$. In the estimation scenario when supplier estimates a lower cost, it leads to higher expected effort of manufacturer and consequently higher expected demand which can lead to a supply level higher than required and when the cost is estimated higher it can lead to lower supplier than required, both leading to supply chain inefficiency. To cope with this inefficiency, we proposed the coordination mechanism as shown in the Table, which leads to less profit variation of actors and no variation of whole supply chain profit in comparison with the decisions under symmetric case which is 542.3 $\leq \pi_s \leq$ 602.5, 398.3 $\leq \pi_m \leq$ 455.5 and $\pi_{sc} = 1000.8$. The variation in actors' profits depends on the ex-ante negotiation on the γ. As an example, when they set γ as 0.57, the following profits are obtained: $\pi_s = 570.7$, $\pi_m = 430.1$ and $\pi_{sc} = 1000.8$.

5. Conclusion

Corporate social responsibility and information asymmetry, two well-known topics in economics and management, have recently gained more attention, usually as two separate topics, in the supply chain context. On the one hand, corporate social responsibility practices are a form of management strategy that contributes to sustainable development and on the other hand, information asymmetry between actors has a negative impact on the sustainable development of the supply chain, if not coordinated. We address these two issues together, a gap in the literature, in a dyadic supply chain setting where both actors commit CSR, and they may have private information i.e., bilateral information asymmetry. Both actors should decide on their effort level and price which affect the demand. First, the optimal solutions under information symmetry are determined and then optimal solutions are calculated for two bilateral information asymmetry scenarios: misreporting and

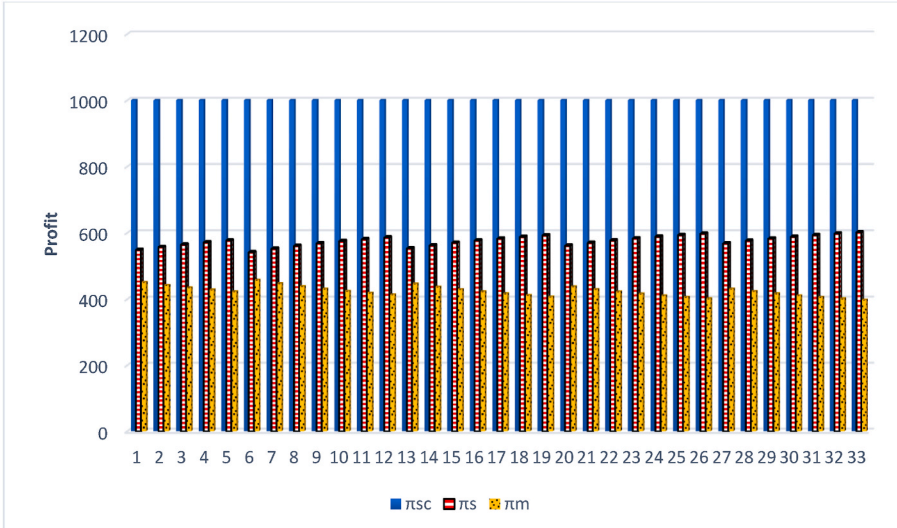

Fig. 9. Profit allocation under coordination mechanism with different ratios.

Table 3
Comparative analysis under different decision structures.

Decision scenario	Supplier's profit	Manufacturer's profit
Symmetric	$\pi_s = 569.23$	$\pi m = 431.56$
Asymmetric-misreporting	$433.37 \leq \pi s \leq 568.05$	$312{,}96 \leq \pi m \leq 409.02$
Asymmetric-estimation	$372{,}46 \leq \pi s \leq 569{,}23$	$123{,}14 \leq \pi m \leq 662.79$
Coordination	$542.3 \leq \pi s \leq 602.5$	$398.3 \leq \pi m \leq 455.5$

estimation. Under two bilateral information scenarios, we examine the effects of information asymmetry on actors' performances by computing profits and demonstrate how information asymmetry can lead to supply chain inefficiency. In order to handle this inefficiency, we propose a coordination mechanism by using AGV mechanism and profit sharing.

It can be noted that there is a mutual incentive between supplier and manufacturer regarding their CSR efforts and information sharing. This mutual incentive leads, as proven and illustrated by numerical examples, to a win-win situation in the symmetric and coordination scenarios, but it leads to the inefficiency of the supply chain and of the actors, even opportunistic ones, in the information asymmetry scenarios. We find that under misreporting scenario, when the actors overstate their costs, they commit less effort which leads to inefficiency in supply chain by decreasing the system's profit and that of each of them, and if only one actor overstates the cost, it imposes more loss to the other actor. In case of estimation scenario, wrong estimation may increase or decrease the profit of an actor but not increase for both. When the supplier underestimates the manufacture's cost the supplier plans higher supply which will not be ordered by the manufacture and will lead to profit loss for the supplier as there will be unsold cost, production cost, inventory cost etc. In case of overestimating manufacture's cost, there will not be sufficient supply and manufacturer, or both will face with shortage or goodwill cost. In both asymmetric information scenarios, the supply chain performance gets worse if the difference between misreported and estimated costs with the real cost values increases more.

We prove and illustrate that our proposed mechanism can coordinate the supply chain by achieving the same efficiency under information symmetry condition and much less profit fluctuation for the actors. In fact, by applying the advantages of profit sharing and AGV mechanism, on the one hand, because of the feature of sharing contracts (Shen et al., 2019), the supplier and manufacturer are naturally encouraged to overcome information asymmetry and on the other hand, they internalize the expected externality imposed on each other (Athey and Segal, 2013) and the whole supply chain objective.

This study can help managers in determining their optimal CSR efforts when they take part in CSR activities. If decentralized decision is the preferred policy of the supply chain actors, the efficient performance can be achieved through the ex-post bargaining as explained in the proposed coordination mechanism. Another managerial insight is that decisions under bilateral information asymmetry, both estimation and misreporting, are unfavorable to the supply chain as a whole and actors except the rare cases in estimation scenarios which maybe favorable to only one actor due to the wrong estimation of the other actor. Applying the proposed mechanism can convert this situation to a win-win strategy and in favor of the whole supply chain. In addition to determining the CSR effort, we answer the following questions: How much to order or produce? What retail or wholesale price to set? How to coordinate? These answers help supply chain managers make optimal decisions.

As many other analytical studies, our model is based on some assumptions, and it has some limits that can be released or substituted with other assumptions to further extend the model at hand. For example, other structures or different supply chain settings, more periods, etc. can be considered. To simplify the analysis, demand is assumed to be deterministic and linear, which can be expanded by considering other well-established deterministic or stochastic demands. To meet the corporate social responsibility challenges and the needs of future generations, it would be interesting (and necessary) to develop and investigate the models focusing more on social criteria beside financial metrics. In this regard, it would be interesting to analyze the coordination mechanisms bay considering CSR priorities of actors (Awan et al., 2019). Another extension is analyzing CSR decisions through a negotiation-based algorithm with mutual adjustments (Taghipour and Frayret, 2012 & 2013) to achieve supply chain coordination. These types of algorithms reflect the dynamic nature of negotiation, a reality in practice, between actors instead of imposing an actor's decisions or assigning a passive role to an actor.

CRediT authorship contribution statement

Mohammadali Vosooghidizaji: Conceptualization, Methodology, Validation, Resources, Writing – original draft, Writing – review & editing, Visualization. **Atour Taghipour:** Conceptualization, Validation, Writing – review & editing, Supervision. **Béatrice Canel-Depitre:** Conceptualization, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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