Article

Efficient Supply Chain Contracting with Loss-averse Players in Presence of Multiple Plausible Breaches

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ABSTRACT

The legal literature distinguishes between the liquidated damage and the penalty clauses in contracts, and holds that penalties designed for the prevention of breach are excessive compared to the liquidated damages. In an efficient supply chain contract, the penalty must satisfy the participation and incentive compatibility constraints of the signatories. Considering loss-averse players, we have calculated optimal penalties in a supply chain contract and compared those with the liquidated damages. Two possible breaches are considered – a breach in quality of the delivery and a breach in the process. In the absence of any penalty, a process breach reduces the supplier's delivery risk and cost of delivery. Determining the parametric conditions for efficient contracts, numerically we show the effects of various variables on the zone of efficient contract. We show that the optimal penalties need not be excessive compared to the liquidated damages.

KEYWORDS

Contract, Liquidated Damage, Loss-aversion, Penalty, Supply Chain

INTRODUCTION

Contracts stipulate an agreed amount of damage upon the breach of a base obligation. If there is a reasonable forecast of the provable injury resulting from the breach, and the compensation is decided based on that forecast, then the enforceable compensation is known as liquidated damage. If the compensation is excessive, then it is termed as a penalty, which has restricted enforceability under certain legal systems. The legal literature defines liquidated damage as the sum that a promisor owes the promisee in case of a breach by the promisor, if such a clause is present in the contract (De Geest & Wuyts 2000; Edlin & Schwartz 2003). Historical evidence and legal verdicts indicate that the liquidated damage clause must establish a reasonable prediction of the provable injury resulting from the breach (Holdsworth 1924; Goetz & Scott 1977 etc.). However, the penalty clause penalizes the promisor, and if a penalty clause is present in the contract, the non-breaching party will be limited to the conventional damage measure, whenever the clause is enforced (Goetz & Scott 1977). Martin (2018) describes a case wherein a buyer is in a long-term agreement with a supplier to purchase soccer balls at $6 per ball. The buyer, located in a developed country, follows a company human rights policy (CHRP), which all its suppliers must adhere to. The CHRP prohibits the use of child labor in production. If it gets disclosed that the supplier, located in a developing country, is employing child labor in manufacturing the balls, the buyer's reputation is damaged, resulting in a loss of sales of soccer balls and other products. If the contract includes the liquidated damages clause, the buyer should *ex-ante* stipulate the amount of its expected loss caused by the lost sales and the damages to its goodwill. The

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buyer can then recover the reasonable compensation from the supplier. However, if the buyer specifies an excessive amount (more than the reasonable amount, according to the forecast of provable damages) in the contract, in case of a breach of the CHRP, it becomes a penalty.

This paper focuses on efficient contracting in supply chains. An efficient contract ensures that no party has any incentive to breach the clauses included in the contract. A supply chain requires an efficient contract to be operationally and financially efficient. In the absence of an efficient contract, breaches that affect the operational efficiency of the supply chain occur. Breaches can result in a waste of resources and loss of reputation. Penalty clauses are commonplace in supply-chain contracts, and it influences the accuracy of delivery in a considerable way. In case of damage or deviation, a penalty clause imposed by the promisee need not tally with the reasonable amount that should be charged to the promisor. An efficient contract should include a penalty clause such that none of the parties declines to sign it, i.e., their participation constraint is satisfied, and the promisor is incentivized not to breach the contract after signing (Hart 1988; Holmstrom & Milgrom 1991). A comprehensive review of supply-chain contracting under information asymmetry is available in Shen, Choi & Minner (2019). Previous literature has utilized the penalty clause to design efficient contracts using the principal-agent framework (Lutze & Özer 2008; Gan et al., 2010). However, no research compares the penalty in an efficient contract with liquidated damage.

Supply chains should focus on cost and response-time reduction (Singh & Kumar 2020), reliable and sustainable green practices (Gupta & Singh 2020) and socially desirable practices (Agrawal, & Singh 2020). In view of that, we have designed penalty amounts for an efficient procurement contract, considering that the supplier may breach the contract in two respects – the quality of the delivered product and the process of its production. The supplier may breach the contract and adopt a standard process, instead of the process stipulated in the contract, to avoid production uncertainty and to reduce cost. For example, consider the case of soccer ball suppliers mentioned earlier. If the suppliers attempt to deliver the stipulated quality without employing child labor, their cost will increase because adult labor is more expensive. According to the standard procedure, the supplier delivers a specific quality by employing child labor. However, if the buyer gets to know that the supplier employed child labor, then the supplier will be penalized because the buyer loses goodwill. On the other hand, if employing of adult labor results in quality degradation, the value of the buyer erodes, and the supplier gets subjected to a penalty due to quality degradation. We have not only identified the penalty amounts for the two plausible breaches that are required to make the contract efficient but have also illustrated the zones of efficient contract under different parametric conditions. We then compare the corresponding liquidated damages to the range of penalties. We show that a penalty need not always be excessive compared to the liquidated damage.

Excluding a couple of papers (Deng et al., 2013; Zhang et al., 2014), the literature on supply-chain contracting assumes the buyers and suppliers to be risk-neutral, even though the penalty amount in an efficient contract depends on the behavior of the supplier with respect to risk and loss. In this paper, we have identified the penalty that makes the contract efficient when the signatories are loss-averse. Only exceptions are Zhang et al. (2014) and Deng et al. (2013). Zhang et al. (2014) developed a model considering a risk-neutral buyer and a risk-averse supplier under cost information asymmetry. Deng et al. (2013) studied a revenue-sharing contract under the supplier's loss-averse behavior. But none of these two papers studied the two plausible breaches within the scope of contract efficiency.

In view of this lacuna in the extant literature, this paper addresses the following research questions.

R1. In the presence of two plausible breaches, in quality and in process, how much penalty (for each breach) is required to make the contract efficient if the signatories are loss-averse?
R2. Is the penalty excessive compared to the corresponding liquidated damage?

There exists a principal-agent game at the heart of the problems that we intend to address through the abovementioned research questions. Here, the buyer is the principal who might be affected by the actions of the supplier, who is the agent. Hence, a principal-agent framework is most suitable for addressing the abovementioned contract related issues discussed above. To address the first research question, R1, we have developed a principal-agent model of the contract, considering two plausible breaches and loss-averse players. Based on the model, we have identified the participation and incentive compatibility constraints of the buyer and supplier. Using these constraints, we determined the conditions on the penalty required to make the contract efficient, considering each plausible breach. We show that the combination of penalties for each breach, required for an efficient contract, depends on several variables and parameters. Through a numerical example, we demonstrate how the ranges of penalty values vary with changes in the variables. This numerical example facilitated the answer to the latter research question, R2, by enabling us to compare the penalty and the corresponding liquidated damage.

The rest of the paper is organized as follows. In Section 2, we have reviewed the relevant literature and have developed the model in Section 3. In Section 4, we have constructed a numerical example and identified the combinations of the penalty amounts that make the contract efficient. Moreover, we have compared the ranges of penalty to the corresponding liquidated damage. In Section 5, we have discussed the results, drawn managerial implications and have pointed out the scope of future research. Finally, in Section 6, we have concluded the paper highlighting our contribution to the literature of supply-chain contracting.

RELEVANT LITERATURE

In this section, we will review four different strands of literature. First, we will examine the legal literature that distinguishes liquidated damages from penalty. We will then explore the literature on delivery risks in supply-chains. In this section, we will also discuss the significant papers that discuss the different aspects of Supply Chain Contracting (SCC). However, these papers do not incorporate either liquidated damage or loss-aversion in their respective models. Nevertheless, the literature on loss-aversion in supply-chain management is growing, which we will discuss at the end of this section.

THE DIFFERENCE AND CONNECTION BETWEEN THE CLAUSES OF LIQUIDATED DAMAGES AND PENALTY

When the signatories include a liquidated damages provision in the contract, upfront they agree on a certain computation of potential damages before a breach of the contract ever occurs. Coldwell et al. (2016) and Reed (2018) use the example of Gator Apple, LLC v. App. Tex. Rests., Inc., to conclude that "a liquidated damages clause in a contract is an advance settlement of the anticipated actual damages arising from a future breach." According to De Geest & Wuyts (2000), if the estimated compensation is under-compensatory, the term "under-liquidated damage" is used, and if the assessed compensation is deliberately over-compensatory, the term "penalty" is employed. The confusion around the penalty clauses arises when distinguishing the *ex-ante* and *ex-post* valuation of losses is not possible (Rea Jr., 1984). In American courts, generally, the reasonableness of *ex-ante* loss valuation is considered while determining whether the clause in the contract is a liquidated damages clause or a penalty clause. According to the old English law, the penalty and the liquidated damages clause are distinguished from a perspective of intention. Penalty is applicable if the intention is to secure the performance of the contract whereas, liquidated damages are applicable if the intention is to assess the damages for the breach of contract (Benjamin, 1960). Chung (1992) shows that penalties can mitigate the problem of social inefficiency caused by unreasonable liquidated damages by placing a cap on the enforceable liquidated damages.

SUPPLY-CHAIN CONTRACTING AND DELIVERY RISKS

Supply chain coordination and effectiveness of supply chain contracts, in presence of various risks, have been studied extensively in the literature. Aviv (2001) shows that collaborative forecasting can reduce uncertainty in the supply-chain. The benefits of collaborative forecasting depend on the relative bargaining power of the supply-chain partners, the supply side agility, and the internal service rate (Aviv, 2007). The effects of supply yield risk on supply-chain management in a single-period setting (e.g., Yano & Lee, 1995; Gupta & Cooper, 2005; Keren, 2009; Güler & Bilgiç, 2009 and Li et al., 2012) and multi-period settings (e.g., Tang, 2006 and Vakharia & Yenipazarli, 2009) constitute a substantial part of the extant literature. Tang & Yin (2007) studied the role of updating supply yield information in a dyadic supply-chain with supply uncertainty. Liu et al. (2010) studies the effects of supply uncertainty on firm performance under joint marketing and inventory decisions in a single-period setting. Tang & Kouvelis (2011) studies supplier diversification strategies in the presence of yield uncertainty and buyer competition. The literature on revenue sharing contracts studies the impact of various uncertain factors, including supplier's lead time (Hou et al. 2009), budget constraint (Feng et al. 2015) and presence of third-party logistics service providers (Giri & Sarker 2017).

While a breach may be the consequence of associated risk (Rangel et al., 2015), the contract should be designed such that the agent intends to maximize the expected payoff or utility of the principal. Negotiating a penalty clause into a contract may be a risk-reducing strategy for the buyer (Sweeney et al., 1973; Mitchell 1995). Yao et al. (2010) and Gunasekaran et al. (2015) emphasize the delivery risk in sourcing contacts. A contract that specifies a fixed lead-time requirement and charges a late fee for outstanding orders is efficient (Cachon & Zhang 2006; Lutze & Özer 2008; Li et al. 2012).

Hu et al. (2013) use a principal-agent framework to study how buyers can incentivize suppliers' investment in capacity restoration. Xu & Lu (2013) investigates the effect of supply uncertainty in price-setting newsvendor model. Cho & Tang (2013) study advance-selling strategies in a supply-chain under uncertain supply and demand. However, in most of these models, the principal and agent are assumed to be loss-neutral. A scrutiny of the literature on SCC and related risk reveals that certain relevant issues have not been addressed yet. In Table 1, we summarize the aspects of contracting that have been covered in the extant literature, along with the features of the present study, demonstrating the gap in the research.

LOSS-AVERSION IN SUPPLY-CHAIN

The loss-aversion research is largely based upon the prospect theory proposed by Kahneman & Tversky (1979). Schweitzer & Cachon (2000) use it in operations and supply-chain management in relation to the newsvendor model. The newsvendor problem under loss-aversion was studied in the contexts of reference target (Wang & Webster 2009), equilibrium order quantity (Wang 2010; Liu et al., 2013), multiple ordering opportunities and market information updating (Ma et al. 2012). Shen, Pang, & Cheng (2011) study the component procurement problem for a loss-averse retailer, who is confronted with a single-whole-sale-price contract and a spot purchase opportunity. Ma et al. (2017) considers the manufacturer as a loss-averse newsvendor and studies its ordering decisions with supply and demand uncertainties. Rubin et al. (2018) study the fundamental question of quality and quantity tradeoff in the presence of loss-aversion. Channel coordination in presence of a loss-averse retailer has been studied in Wang & Webster (2007) and Deng et al. (2013). While loss-aversion has been assumed in the theoretical literature, there are studies that delved into empirical testing to determine whether firms' behavior is consistent with the assumption of loss-aversion. A comprehensive review of such studies is available in Alexander et al. (2021).

The theory of unconscionability of a contract prompts an examination of the influence of loss-aversion in the context of liquidated damages or penalty doctrine. Marrow (2001) elaborates on the importance of risk and loss-related behavior of different parties (i.e., buyer and supplier in a supply-chain) in deciding whether liquidated damages are underestimated, overestimated or appropriate. While agents' risk behavior has been studied in the literature of efficient contracts, very few have studied the loss-aversion behavior of the signatories of a contract.

Table 1. Some Major Literature Capturing Various Aspects of Contracting

Authors	SCC / Contract	Principle Agent Game	Supply Chain Delivery Risk	Loss Aversion	Penalty	Liquidated Damage
Cachon & Lariviere (2001), Cachon (2004), Cachon & Lariviere (2005), Ertogral & Wu (2001), Yao et al. (2010), Zhao et al. (2010), Agrell et al. (2004), Tsay & Lovejoy (1999), Shafiq & Savino (2019)	√	√				
Deng et al. (2013)	√	√		√		
Dai et al. (2016)	√		√			
Mathur & Shah (2008), Frascatore & Mahmoodi (2008), Nagarajan & Sošić (2008), He & Zhang (2008), Gan et al. (2010)	√	√			√	
Giovanni (2020), Tao et al. (2021)	√	√	√			
Katok & Wu (2009), Wang & Webster (2007), Dubey et al. (2018), Eeckhoudt et al. (2018), Vipin & Amit (2017)	√	√		√		
Lee et al. (2018), Li et al. (2021), Meza & Webb (2007)	√	√		√	√	
Li et al. (2016)	√	√	√	√	√	
Stole (1992)	√	√				√
The Present Study	√	√	√	√	√	√

The studies regarding supply-chain contracts with penalty clauses are primarily restricted to designing efficient contracts and ensuring correct delivery. However, liquidated damage due to incorrect process has been largely overlooked in the extant literature. There is no paper that designs an efficient contract considering breaches in delivery as well as in process. In this paper, we fill this gap

by determining the optimal penalties that should be announced *ex-ante* to make the contract efficient. We have assumed that both the buyer and the supplier are loss-averse.

THE MODEL

We consider a general situation wherein a delivery contract is signed between a loss-averse buyer (she) and one of her loss-averse suppliers (he). We consider loss aversion because of two reasons. First, empirical evidence suggests that firms are loss-averse (see Alexander et al., 2021). Second, our model specification (given later in this section) allows for loss-neutrality, depending on the value of the coefficient of loss aversion.

After the contract is signed, the supplier can deliver a product or service as per the conditions specified in the contract (e.g., following the buyer's company policy, and abiding by the performance specified variables, which may be superior to or at par with the common industry practice) or by following a standard procedure, as per industry practices, but not adhering to the contract. In this paper, the former is termed as 'the correct process' and later is called 'the standard process'. If the supplier attempts a correct delivery following the correct process, he must incur some extra costs in doing so. Moreover, correct delivery following the correct process is an uncertain event. The uncertainty is caused by the adoption of a correct process in a departure from the standard process that the supplier is used to. The supplier receives the full payment without needing to pay any penalty if the delivery is correct. However, according to the liquidated damages or penalty clause in the contract, if the supplier fails to deliver the product or service correctly, he is required to pay the penalty for incorrect delivery. On the other hand, when the supplier attempts a correct delivery following the standard process, there is no uncertainty about the correct delivery because the process is common, comparatively easy and the supplier is familiar to the process. However, the standard process may not conform to the buyer's norm(s) (e.g., ethical / environmental standard, etc., not related to the quality of the product or service). If the supplier delivers the product or service correctly following a standard process, he can still be penalized (for not following the correct process) in case the buyer finds out. The rationale for imposing the penalty is that the standard process hampers the buyer's reputation and thus, *ex post*, the product value degrades. However, the supplier does not get penalized if the buyer is unaware of the fact that the process is incorrect. After the contract is signed, the buyer does not have control over delivery. Therefore, the contract is subject to moral hazard. Hence, while designing the contract, the buyer must ensure that the supplier signs the contract, and after signing it, attempts correct delivery following the correct process.

The notations used in this paper are defined in Table 2.

Table 2. List of Notations

Notation	Definition
y	*Buyer's payment to the supplier in case of a delivery*
p_N	*Penalty imposed by the buyer on the supplier if the supplier does not follow the correct process and the buyer gets to know that*
p_Q	*Penalty imposed by the buyer on the supplier in case of incorrect delivery*
V_H	*The Buyer's value obtained from the product / service in case of a correct delivery*
V_L	*The Buyer's value obtained from the product / service in case of an incorrect delivery*
V_{L1}	*The Buyer's value obtained from the product / service in case the buyer gets to know that the correct process was not followed in production*
I_H	*The cost incurred by the supplier if the correct process is followed*
I_S	*The cost incurred by the supplier if the standard process is followed*
ρ	*The probability of a Correct delivery with the correct process*
θ	*The probability that the buyer does not get to know that the correct process was not followed (and hence, perceives the delivery as 'correct' when the standard process is followed by the supplier)*
K_B	*The coefficient of loss-aversion for the buyer*
K_S	*The coefficient of loss-aversion for the supplier*

Assumption 1: $V_L < V_H$
(V_H - V_L) is the magnitude of the buyer's value loss due to quality degradation.

Assumption 2: $V_{L1} < V_L < V_H$
Even though there is no quality degradation when the standard process is followed, the buyer's value erodes due to loss of goodwill, in case the market becomes aware of incorrect process. The buyer's value erosion, caused by the loss of goodwill, is larger than the value erosion caused by quality degradation.

Assumption 3: $I_S < I_H$
(I_H - I_S) is the additional cost borne by the supplier, when the correct process is followed.

Assumption 4: $1 \leq K_B < 1/\vartheta$ and $1 \leq K_S < 1/(1 - \rho)$
The buyer (supplier) is loss-neutral when $K_B = 1$ ($K_S = 1$). The upper bounds are required to ensure that the perceived probabilities of losses remain less than 1.

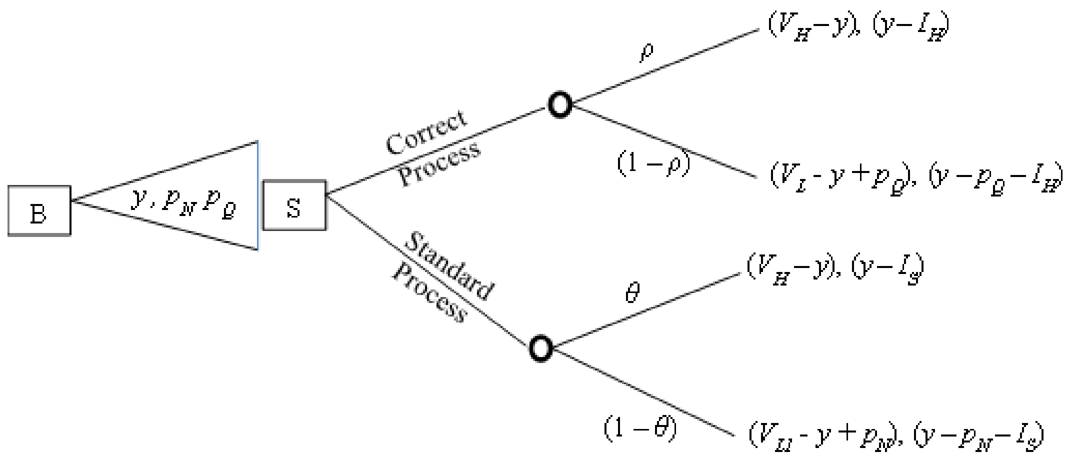


Figure 1. Game in Extensive Form

Here, the buyer is the principal, and the supplier is the agent. First, the buyer offers a contract specifying p_N, p_Q and y. After observing and accepting the contract, the supplier decides whether to follow the correct process or not. If the supplier follows the correct process, he achieves correct delivery with a probability ρ. However, he fails to achieve correct delivery after following the correct process, with a probability (1 – ρ), and in that case the supplier must pay the penalty for delivery breach. If the correct process is not followed, i.e., the standard process is followed, the supplier achieves the correct delivery with certainty. When the standard process is followed, there is a probability (ϑ) of the buyer remaining unaware of the incorrect process and perceives the delivery as 'correct'. In such a case, the supplier does not pay the penalty for process breach.

PERCEIVED PROBABILITIES OF LOSS-AVERSE PLAYERS

Since the supplier is loss-averse, he overweighs the probability of loss, that is, not achieving correct delivery after following the correct process, by the factor of his loss-aversiveness i.e., K_S. This probability weighing function has been used in behavioral economics literature following Kahneman & Tversky (1979). Therefore, the probability of an incorrect delivery, despite following the correct process, as perceived by the supplier is $(1–\rho)K_S$, and the perceived probability of a correct delivery, after following the correct process, is $(1–K_S+\rho K_S)$. By Assumption 4, $K_S \geq 1$, i.e., the supplier overweighs the probability of incorrect delivery following the correct process. Similarly, when the supplier follows the standard process, the buyer's perceived probability of remaining unaware that the supplier did not follow the correct process is ϑK_B and that of being aware is $(1–\vartheta K_B)$, For the supplier, the respective perceived probabilities are $(1–K_S+\vartheta K_S)$ and $(1–\vartheta)K_S$.

Propositions 1 and 2 outline the conditions under which the buyer's and the supplier's incentive compatibility constraints, and their participation constraints are satisfied. Notably, when the buyer (supplier) is loss-neutral, the parameter K_B (K_S) becomes 1. Hence, our model is general in terms of the players' behavioral attitude towards losses.

Proposition 1: The incentive compatibility constraints for the buyer and supplier for participating in the correct process is satisfied when:

$$\frac{(I_H-I_S)+p_Q(1-\rho)K_S}{(1-\theta)K_S} < p_N < \frac{\rho(V_H-V_L)-\theta K_B(V_H-V_{L1})+(V_L-V_{L1})+(1-\rho)p_Q}{(1-\theta K_B)}$$

Proof: For the buyer, there is an incentive to enforce the correct process instead of the standard process if and only if,

$$\rho\left(V_H - y\right) + (1-\rho)\left(V_L - y + p_Q\right) > \theta K_B (V_H - y) + (1-\theta K_B)(V_{L1} - y + p_N)$$
$$\Rightarrow p_N < \frac{\rho(V_H - V_L) - \theta K_B (V_H - V_{L1}) + (V_L - V_{L1}) + (1-\rho)p_Q}{(1-\theta K_B)}$$

Similarly, For the supplier, there is an incentive to follow the correct process instead of the standard process if and only if,

$$(1 - K_S + \rho K_S)(y - I_H) + (1-\rho)K_S\left(y - p_Q - I_H\right)$$
$$> (1 - K_S + \theta K_S)(y - I_S) + (1-\theta)K_S(y - p_N - I_S)$$
$$\Rightarrow \frac{(I_H - I_S) + p_Q(1-\rho)K_S}{(1-\theta)K_S} < p_N$$

So, the incentive compatibility constraints are satisfied when,

$$\frac{(I_H - I_S) + p_Q(1-\rho)K_S}{(1-\theta)K_S} < p_N < \frac{\rho(V_H - V_L) - \theta K_B(V_H - V_{L1}) + (V_L - V_{L1}) + (1-\rho)p_Q}{(1-\theta K_B)} \quad (1)$$

Proposition 2: The participation constraints for the buyer and supplier for participating in the contract that enforces the correct process is satisfied when:

$$0 < p_Q < \frac{(y - I_H)}{(1-\rho)K_S}$$

Proof: The buyer will participate in the contract if and only if,

$$\rho\left(V_H - y\right) + (1-\rho)\left(V_L - y + p_Q\right) > 0$$
$$\Rightarrow \frac{\rho(V_H - V_L) + (V_L - y)}{(\rho - 1)} < p_Q$$

For $\rho < 1, \frac{\rho(V_H - V_L) + (V_L - y)}{(\rho - 1)} > 0$ if and only if $y > \rho V_H + (1-\rho)V_L$. But since *y* is the price paid by the buyer and $\rho V_H + (1-\rho)V_L$ is the expected value that she obtains, it is impossible that the condition $y > \rho V_H + (1-\rho)V_L$ is true. Therefore, $\frac{\rho(V_H - V_L) + (V_L - y)}{(\rho - 1)} \le 0$. So, the participation constraint for the buyer reduces to $p_Q > 0$.

Similarly, the supplier will participate in the contract if and only if,

$$(1 - K_S + \rho K_S)(y - I_H) + (1-\rho)K_S\left(y - p_Q - I_H\right) > 0$$
$$\Rightarrow p_Q < \frac{(y - I_H)}{(1-\rho)K_S}$$

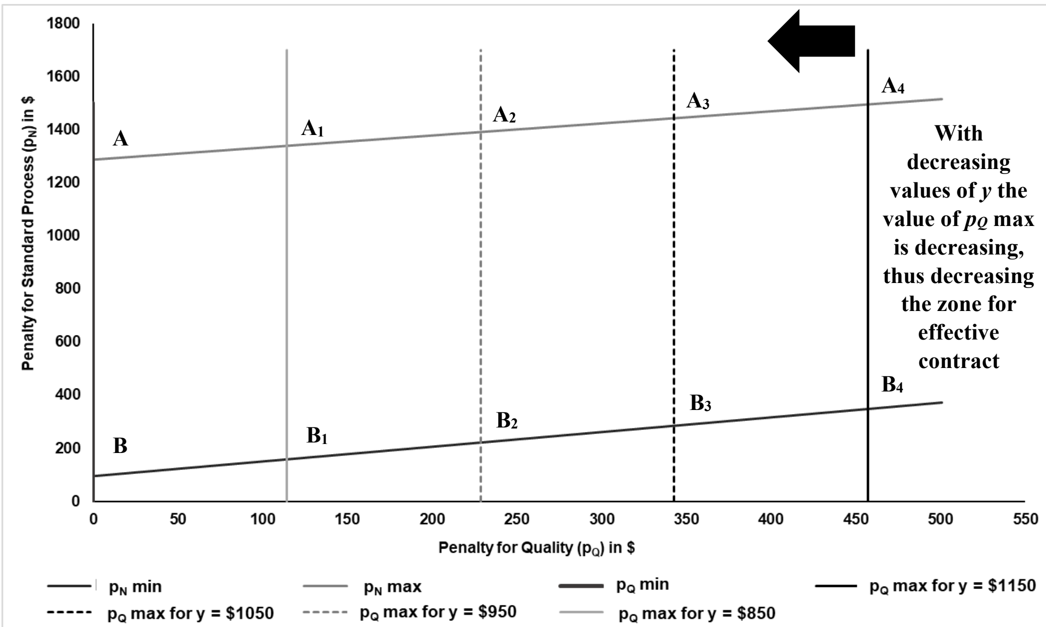
So, the participation constraints are satisfied when $0 < p_Q < \frac{(y - I_H)}{(1-\rho)K_S}$ (2)

NUMERICAL EXAMPLE

The contract is efficient if the supplier agrees to sign the contract, and then chooses the correct process. Both the incentive compatibility and participation constraints are satisfied if and only if equations (1) and (2) hold true. We have plotted the respective graphs of the two equations considering p_Q as the independent variable along the x-axis, and p_N as the dependent variable along the y-axis. The probabilities ρ = 0.5, ϑ = 0.1, K_S = 1.75 and K_B = 1.2, are kept constant across all graphs. The values of each of the variables, i.e., *y*, V_H, V_L, V_{L1}, I_H and I_S, are changed one at a time, keeping other variables constant. The value of ρ is chosen as 0.5 to explain the scenario where correct delivery with the correct process and incorrect delivery with the correct process are equally likely. The probability that the buyer is ignorant of the fact that the supplier is using a standard process instead of the correct one is significantly less than 0.5, as buyers generally conduct inspections. Hence, we took a comparatively small value of ϑ i.e., 0.1. We chose K_B = 1.2 and K_S = 1.75, indicating that the buyer is less loss-averse than the supplier. We have varied the values of V_H, V_L, V_{L1}, I_H and I_S adhering to the

assumptions of the model. Each graph gives us the zone of efficient contract, in the respective cases, such that both the participation and incentive compatibility constraints are satisfied. This method allows us to study the changes in the zone according to the changes in the variables. All graphs are shown below (Figure 2 to Figure 7). Further, in each of the six situations, we have compared the value of the liquidated damages due to incorrect delivery, V_H–V_L, and that due to incorrect (standard) process, V_H–V_{L1}, to the optimal ranges of the corresponding penalty values.

Figure 2 shows how the zone of efficient contract changes as the value of y is decreased. In equation 1, y is not present in the expression for limiting values of p_N, i.e., p_N min and p_N max, and these are depicted by straight-lines BB_4 and AA_4 that do not change with the decreasing values of y.



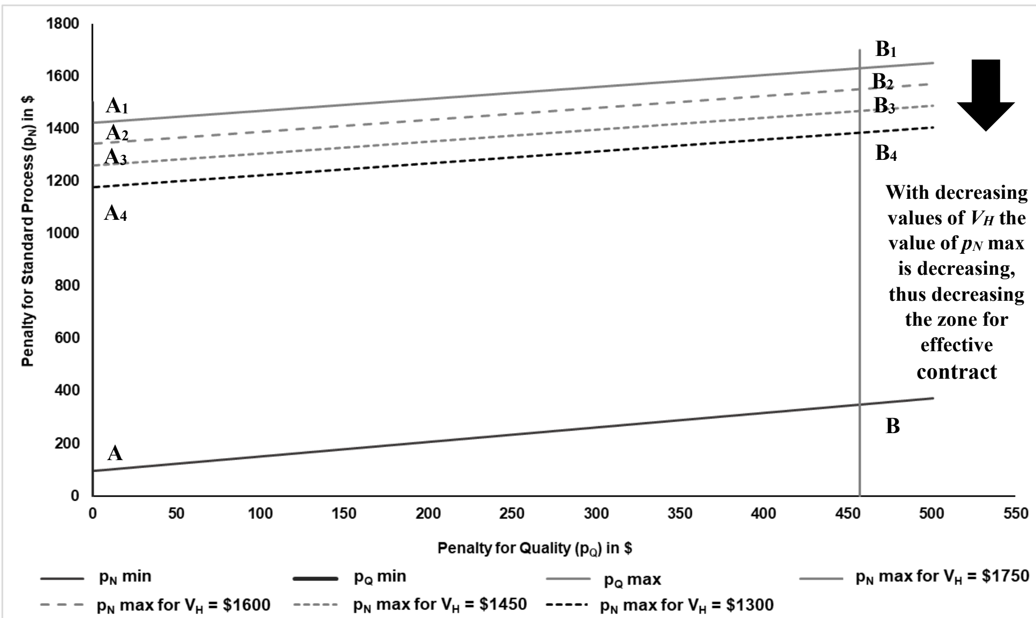
Values of Constants: V_H = \$1500, V_L = \$1250, V_{L1} = \$100, I_H = \$750, I_S = \$600, ρ = 0.5, ϑ = 0.1, K_S = 1.75 and K_B = 1.2

Figure 2. Variation in p_Q and p_N with Decreasing y

In equation 2, the lower limit of p_Q, i.e., p_Q min is 0, which is represented by the straight-line AB, and the upper limit p_Q max decreases with the decreasing values of y depicted by the leftward movement of the straight-line A_4B_4 from its initial position to the position of A_3B_3, A_2B_2 and A_1B_1 respectively. Consequently, the zone of efficient contract decreases from area AA_4B_4B to area AA_1B_1B. So, the zone of efficient contract decreases with a decrease in y when all other variables i.e., V_H, V_L, V_{L1}, I_H and I_S are unchanged. Table 3 compares the liquidated damages, V_H–V_L and V_H–V_{L1}, to the limiting values of the penalties. With a reduction in base payment, y, the upper limit of penalties, p_C and p_N, due to breaches in delivery and process, respectively, come down despite the unchanged value of liquidated damage. When y falls below a threshold, the maximum applicable optimal penalties are less than the liquidated damages. So, the optimal penalty need not be excessive vis-à-vis the liquidated damage.

Table 3. Range of Optimal p_Q and p_N with Variation in y

y	$V_H – V_L$	$V_H – V_{L1}$	p_Q min	p_Q max	p_N min	p_N max
1150	*250*	*1400*	*0*	*457.14*	*95.24 - 349.21*	*1286.36 - 1494.16*
1050	*250*	*1400*	*0*	*342.86*	*95.24 - 285.72*	*1286.36 - 1442.21*
950	*250*	*1400*	*0*	*228.57*	*95.24 - 222.22*	*1286.36 - 1390.26*
850	*250*	*1400*	*0*	*114.29*	*95.24 - 158.73*	*1286.36 - 1338.31*



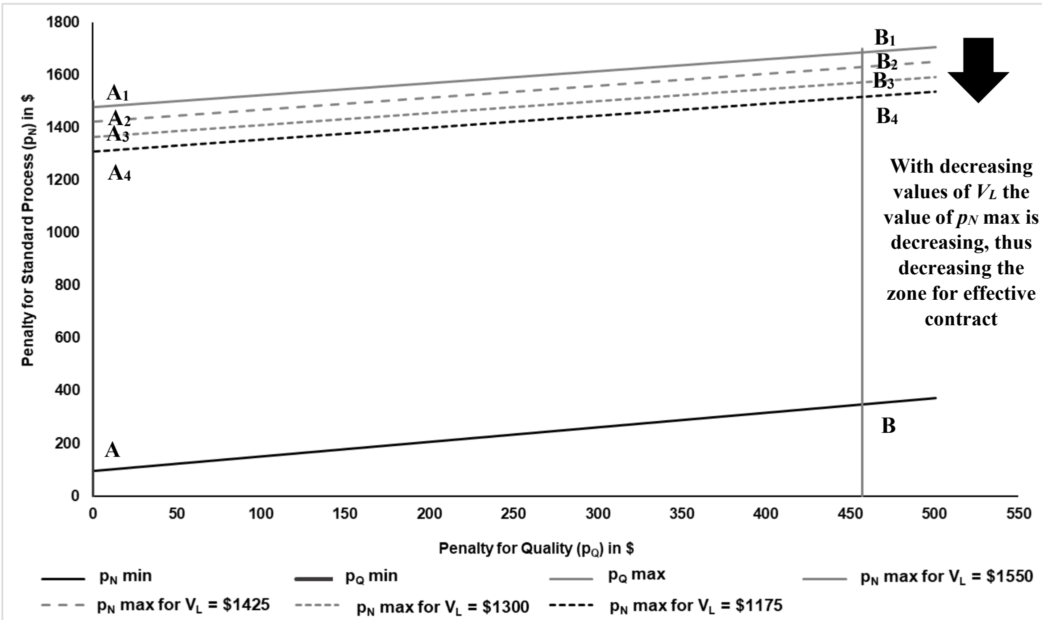
Values of Constants: y = \$1150, V_L = \$1250, V_{L1} = \$100, I_H = \$750, I_S = \$600, ρ = 0.5, ϑ = 0.1, K_S = 1.75 and K_B = 1.2

Figure 3. Variation in p_Q and p_N with Decreasing V_H

Figure 3 shows the change in the zone of an efficient contract when V_H decreases. In equation 1, the value of p_N max decreases with decreasing V_H and this is depicted by the downward movement of the straight-line A_1B_1. Consequently, the zone of optimal contract decreases when V_H decreases and all other variables i.e., y, V_L, V_{L1}, I_H and I_S are unchanged. The comparison of liquidated damages, $V_H – V_L$ and $V_H – V_{L1}$, with the limiting values of the penalties, are given in Table 4. Liquidated damages due to delivery and process breaches increase with an increase in V_H. However, in the presence of loss-aversion, the upper limit of the optimal penalty for delivery breach does not change and that for process breach increases, though not linearly. Beyond a threshold, the maximum applicable optimal penalty becomes smaller than the liquidated damage.

Table 4. Range of Optimal p_Q and p_N with Variation in V_H

V_H	$V_H–V_L$	$V_H–V_{L1}$	p_Q min	p_Q max	p_N min	p_N max
1750	500	1650	0	457.14	95.24 - 349.21	1422.73 - 1630.52
1600	350	1500	0	457.14	95.24 - 349.21	1340.91 - 1548.70
1450	200	1350	0	457.14	95.24 - 349.21	1259.10 - 1466.88
1300	50	1200	0	457.14	95.24 - 349.21	1177.27 - 1385.10



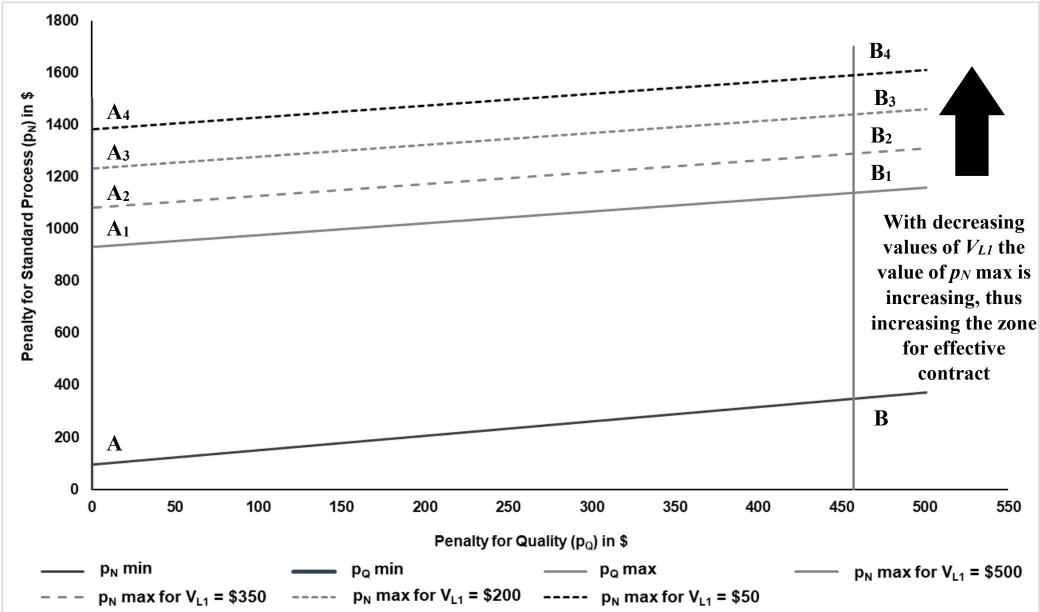
Values of Constants: y = \$1150, V_H = \$1600, V_{L1} = \$100, I_H = \$750, I_S = \$600, ρ = 0.5, ϑ = 0.1, K_S = 1.75 and K_B = 1.2

Figure 4. Variation in p_Q and p_N with Decreasing V_L

Figure 4 shows how the zone of efficient contract varies with a decrease in V_L. By equation 1, p_N max decreases with a decrease in V_L and is depicted by the downward movement of the straight-line A_1B_1. Consequently, the zone of efficient contract decreases when V_L decreases and all other variables remain unchanged. The computation of liquidated damages and the upper limits of p_Q and p_N are given in Table 4. In this case, the band of p_N max decreases, implying that the optimal penalty need not be excessive compared to the liquidated damages.

Table 5. Range of Optimal p_Q and p_N with Variation in V_L

V_L	$V_H–V_L$	$V_H–V_{L1}$	p_Q min	p_Q max	p_N min	p_N max
1550	50	1500	0	457.14	95.24 - 349.21	1477.27 - 1685.10
1425	175	1500	0	457.14	95.24 - 349.21	1420.46 - 1628.25
1300	300	1500	0	457.14	95.24 - 349.21	1363.64 - 1571.43
1175	425	1500	0	457.14	95.24 - 349.21	1306.82 - 1514.61



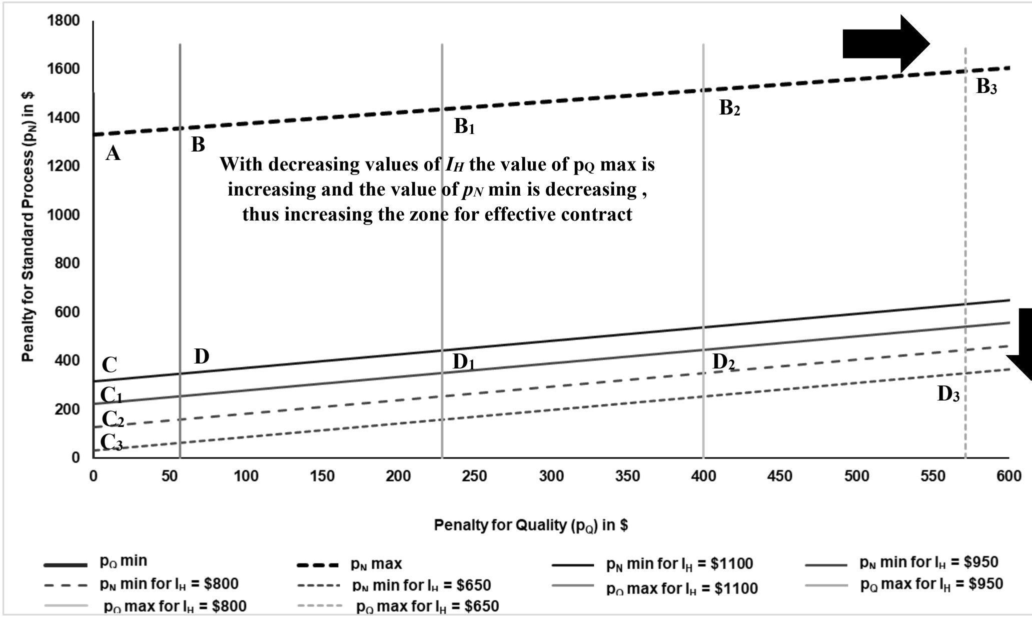
Values of Constants - y = \$1150, V_H = \$1500, V_L = \$1350, I_H = \$750, I_S = \$600, ρ = 0.5, ϑ = 0.1, K_S = 1.75 and K_B = 1.2

Figure 5. Variation in p_Q and p_N with Decreasing V_{L1}

Figure 5 shows changes in the zone of an efficient contract as V_{L1} decreases and all other variables remain unchanged. Comparison of liquidated damage due to standard process, V_H–V_{L1}, and the upper limit of p_N-max is presented in Table 5. It is possible to find an optimal penalty that is less than the liquidated damage, as the lower limit of p_N is less than V_H–V_{L1}. With a reduction in the value of V_{L1}, liquidated damage increases. However, p_N does not increase linearly due to loss-aversion.

Table 6. Range of Optimal p_Q and p_N with Variation in V_{L1}

V_{L1}	V_H–V_L	V_H–V_{L1}	p_Q min	p_Q max	p_N min	p_N max
500	*150*	*1000*	*0*	*457.14*	*95.24 - 349.21*	*931.82 - 1139.61*
350	*150*	*1150*	*0*	*457.14*	*95.24 - 349.21*	*1081.82 - 1289.61*
200	*150*	*1300*	*0*	*457.14*	*95.24 - 349.21*	*1231.82 - 1439.61*
50	*150*	*1450*	*0*	*457.14*	*95.24 - 349.21*	*1381.82 - 1589.61*



Values of Constants - y = \$1150, V_H = \$1500, V_L = \$1350, V_{L1} = \$100, I_S = \$600, $\rho = 0.5$, $\vartheta = 0.1$, $K_S = 1.75$ and $K_B = 1.2$

Figure 6. Variation in p_Q and p_N with Decreasing I_H

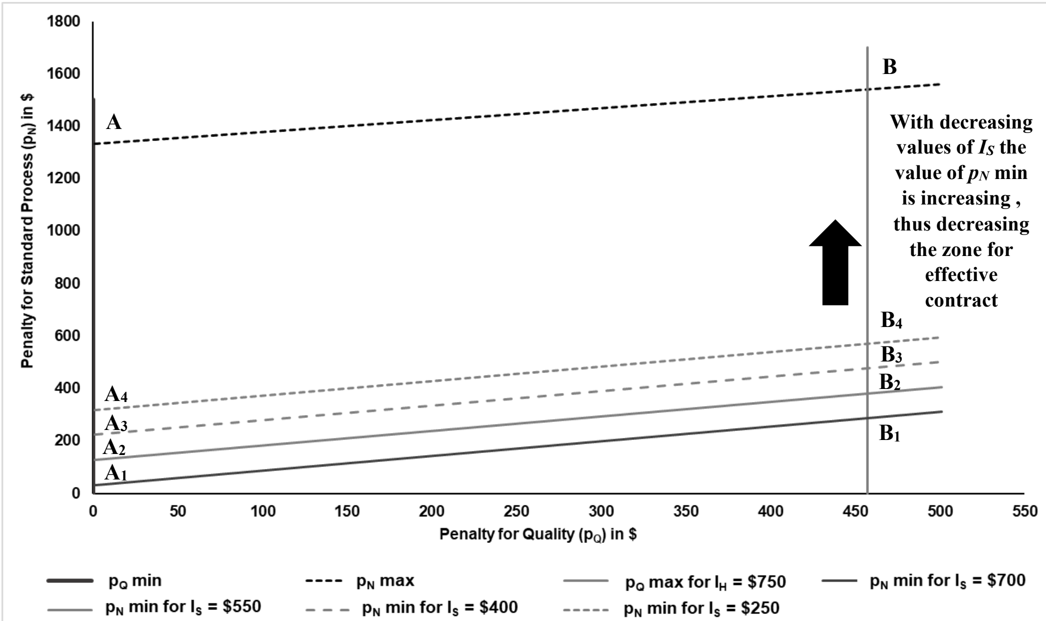
Figure 6 shows how the zone of effective contract changes with a decrease in the supplier's cost under the correct process, I_H. By equation 2, p_Q max increases with a decrease in I_H, and is depicted by the rightward movement of the straight-line BD. By equation 1, p_N min decreases with a decrease in I_H, and is depicted by the downward movement of CD. Consequently, the zone of the efficient contract increases when I_H decreases, and all other variables remain unchanged.

A comparison of liquidated damages and penalties for increasing I_H is shown in Table 7. V_H–V_L and V_H–V_{L1} remains constant, as the buyer's value does not depend on the supplier's cost. In the presence of loss-aversion, the upper limits of p_Q and p_N decrease with increasing I_H. Hence, the optimal penalties become smaller than the liquidated damage after I_H crosses a threshold.

Table 7. Range of Optimal p_Q and p_N with Variation in I_H

I_H	V_H–V_L	V_H–V_{L1}	p_Q min	p_Q max	p_N min	p_N max
650	*150*	*1400*	*0*	*571.43*	*31.75 - 349.21*	*1331.82 - 1591.56*
800	*150*	*1400*	*0*	*400.00*	*126.98 - 349.21*	*1331.82 - 1513.64*
950	*150*	*1400*	*0*	*228.57*	*222.22 - 349.21*	*1331.82 - 1435.71*
1100	*150*	*1400*	*0*	*57.14*	*317.46 - 349.21*	*1331.82 - 1357.79*

Figure 7 shows changes in the zone of an efficient contract with a decrease in the supplier's cost under standard process, I_S, when and all other variables remain unchanged. The computation of liquidated damages and the upper limits of p_Q and p_N are given in Table 8.



Values of Constants - y = \$1150, V_H = \$1500, V_L = \$1350, V_{L1} = \$100, I_H = \$750, ρ = 0.5, ϑ = 0.1, K_S = 1.75 and K_B = 1.2

Figure 7. Variation in p_Q and p_N with Decreasing I_S

Table 8. Range of Optimal p_Q and p_N with Variation in I_S

I_S	$V_H–V_L$	$V_H–V_{L1}$	p_Q min	p_Q max	p_N min	p_N max
250	*150*	*1400*	*0*	*457.14*	*317.46 - 571.43*	*1331.82 - 1539.61*
400	*150*	*1400*	*0*	*457.14*	*222.22 - 476.19*	*1331.82 - 1539.61*
550	*150*	*1400*	*0*	*457.14*	*126.98 - 380.95*	*1331.82 - 1539.61*
700	*150*	*1400*	*0*	*457.14*	*31.75 - 285.71*	*1331.82 - 1539.61*

Table 9. Sensitivity of Optimal p_N (variation in y) to Changes in ϑ and K_b

		K_b=1.1		K_b =1.2		K_b =1.3	
	***y* value**	**p_N min**	**p_N max**	**p_N min**	**p_N max**	**p_N min**	**p_N max**
ϑ=0.05	*1150*	*90.23 - 330.83*	*1280.95 - 1498.64*	*90.23 - 330.83*	*1293.62 - 1488.15*	*90.23 - 330.83*	*1306.42 - 1477.54*
	1050	*90.23 - 270.68*	*1280.95 - 1444.22*	*90.23 - 270.68*	*1293.62 - 1439.52*	*90.23 - 270.68*	*1306.42 - 1434.76*
	950	*90.23 - 210.53*	*1280.95 -1389.80*	*90.23 - 210.53*	*1293.62 - 1390.88*	*90.23 - 210.53*	*1306.42 - 1391.98*
	850	*90.23 - 150.38*	*1280.95 - 1335.38*	*90.23 - 150.38*	*1293.62 - 1342.25*	*90.23 - 150.38*	*1306.42 - 1349.20*
ϑ=0.1	*1150*	*95.24 - 349.21*	*1273.60 - 1504.74*	*95.24 - 349.21*	*1286.36 - 1494.16*	*95.24 - 349.21*	*1299.43 - 1483.33*
	1050	*95.24 - 285.72*	*1273.60 - 1446.95*	*95.24 - 285.72*	*1286.36 - 1442.21*	*95.24 - 285.72*	*1299.43 - 1437.36*
	950	*95.24 - 222.22*	*1273.60 - 1389.17*	*95.24 - 222.22*	*1286.36 - 1390.26*	*95.24 - 222.22*	*1299.43 - 1391.38*
	850	*95.24 - 158.73*	*1273.60 - 1331.38*	*95.24 - 158.73*	*1286.36 - 1338.31*	*95.24 - 158.73*	*1299.43 - 1345.40*
ϑ=0.15	*1150*	*100.84 - 369.75*	*1265.27 - 1511.63*	*100.84 - 369.75*	*1278.05 - 1501.05*	*100.84 - 369.75*	*1291.30 - 1490.06*
	1050	*100.84 - 302.52*	*1265.27 - 1450.04*	*100.84 - 302.52*	*1278.05 - 1445.30*	*100.84 - 302.52*	*1291.30 - 1440.37*
	950	*100.84 - 235.29*	*1265.27 - 1388.45*	*100.84 - 235.29*	*1278.05 - 1389.55*	*100.84 - 235.29*	*1291.30 - 1390.68*
	850	*100.84 - 168.07*	*1265.27 - 1326.86*	*100.84 - 168.07*	*1278.05 - 1333.80*	*100.84 - 168.07*	*1291.30 - 1341.00*

SENSITIVITY ANALYSIS

In our numerical example, we have taken specific values of the parameters ϑ, K_B and K_S. To validate the robustness of our results, we have conducted a sensitivity analysis under varying values of the parameters. Our analysis shows that the effect of changing the values of y, V_H, V_L, V_{L1}, I_H and I_S, on the directions of changes in the ranges of p_Q and p_N, is independent of the values of ϑ, K_B and K_S. For example, with a reduction of y, the upper limits of p_Q and p_N come down resulting in a reduced zone of efficient contract. This fundamental result holds even if the parameter values change. However, some of boundary conditions on the penalties required for efficient contracting might change. For example, the ranges of p_N change nominally with changes in the values of ϑ and K_B. The same has been demonstrated in Table 9.

Similarly, as V_H and V_L decrease, the upper limit of p_N reduces irrespective of the parameter values taken for the analysis. Only the boundary values of p_N changes nominally. Due to limitation of space, we did not present the entire result of the sensitivity analysis.

DISCUSSION AND MANAGERIAL IMPLICATIONS

The graphs in Figures 5 and 6 indicate that the zone for efficient contract increases with decreases in the values of V_{L1} and I_H. If the supplier's cost of following the correct process (I_H) decreases, it becomes easier for the supplier to agree to a larger penalty imposed by the buyer and hence, a reduction in I_H increases the zone of efficient contract. V_{L1} is the value obtained by the buyer from the product when she realizes that the supplier did not follow the correct process. The buyer loses value due to a loss in goodwill. The smaller is the value of V_{L1}, the greater is the loss. A decrease in value of V_{L1} increases the liquidated damage, in case of a breach, which subsequently increases the zone of efficient contract.

In contrast, as shown in Figures 2, 3, 4 and 7, the zone of an efficient contract shrinks with a decrease in the value of the studied variable. With a decrease in the value of contracted payment to the supplier (y), the viable penalty that satisfies the supplier's participation constraint decreases.

Consequently, the zone of efficient contract shrinks. With a reduction in the buyer's value from receiving a correct delivery that followed the correct process (V_H), the liquidated damages, i.e., ($V_H - V_L$), in the case of incorrect delivery, and ($V_H - V_{L1}$), in the case of incorrect process, reduce. This also results in the shrinkage of the zone of efficient contract. A reduction in the buyer's value from receiving an incorrect delivery (V_L), *ceteris paribus*, increases the liquidated damage ($V_H - V_L$), keeping ($V_H - V_{L1}$) unchanged. As a result, it becomes more difficult to incentivize the supplier to follow the correct process. Consequently, the zone of efficient contract shrinks. Similarly, a decrease in the supplier's cost from following a standard process (I_S) makes it more difficult to incentivize the supplier to follow the correct process, thereby reducing the zone of efficient contract.

MANAGERIAL IMPLICATIONS

The SCC literature underexplores the issue of liquidated damage clause in the supply chain contracts, with none of the existing models addressing liquidated damage related issues. On the contrary, evidence from the industry suggests that liquidated damage clause primarily covers the following two aspects: (i) delay in delivery and (ii) non-performance issues. In case of a delay by the supplier (promisor), a reasonable penalty agreed upon by both the parties, at the time of contracting, is charged by the buyer (promisee). Any required resolution is done by a mutual settlement outside the court. In the case of non-performance i.e., deviation from the tolerance allowed in the contract, rejection of the order and subsequent court cases are possible. There is a general perception that, in the manufacturing sector, the buyer possesses more power than the supplier and hence, the supplier hesitates to go to the court of law for conflict resolution. However, in practice, the buyer seldom goes to court because they have the power as well as high stake, and therefore, a mutual settlement outside of the court, and/or rejection of the order, is more beneficial to them. In the case of non-performance, the buyer may approach the court of law, but this action is common only when a) the resolution is not possible amicably, and/or b) the recovery option is not available, and/or c) the risk and/or cost is exceptionally high. Big development projects, like plant or boiler commissioning projects, may be cited as the examples of such situations. For instance, in a gas-commission plant, there are several output specifications which the supplier may require from its buyer, and accordingly, the contract may be signed. Now, it may so happen that because the buyer misses certain specification(s) in the input drawing and/or checklist, the supplier delivers a plant which deviates from the requirement of the buyer. In this case, if the delivery is subjected to rejection by the buyer, because recovery option is no more viable (as the plant has already been set up), the supplier goes to the court of law if an amicable resolution is not possible. To avoid this *ex-post* situation, it is necessary to design efficient and equitable contracts. The present study, therefore, attempts to explore this paradigm.

Determination of the zone of efficient contract, under a given parametric condition, provides the signatories of the contract with a set of acceptable penalties (p_Q, p_N) that induces the supplier to follow the correct process. This helps the buyer and the supplier in signing an *ex-ante* contract with suitable penalty clauses and aids the court of law in determining whether the penalty included in the contract is reasonable, in the case of a dispute. The following insights are obtained directly from our numerical analysis:

- If the base payment is small, the supplier will not sign the contract unless the penalties charged upon a breach, are less than the corresponding liquidated damages.
- If the buyer's value of the product that follows correct delivery and process is sufficiently high, a loss-averse supplier will not sign the contract unless the penalties are less than the corresponding liquidated damages.

- If the buyer's value of the product following a standard process (i.e., not following the correct process) is sufficiently low, then a loss-averse supplier will not sign the contract unless the penalty due to process breach is less than the liquidated damage.
- If the supplier's cost of following the correct process is sufficiently high, then they will not sign the contract unless the penalties for delivery and process breaches are less than the corresponding liquidated damages.

From our numerical examples, it is evident that the optimal penalties should not exceed the liquidated damages. At the same time, the buyer must include a sufficiently large penalty if their value erosion resulting from a breach in the process is very large. The suppliers also can determine whether a penalty included in a contract is reasonable; and thus, our results can help suppliers decide whether to sign a contract with a penalty clause or not. Supply-chain managers and practitioners in the field of operations and supply-chain management, may use these insights in preparing their professionals for signing *ex-ante* contracts with penalty clauses.

CONTRIBUTION TO THE LITERATURE

This study contributes to the literature on supply chain contracting in two different ways. First, we have considered multiple plausible breaches and compared the optimal penalties to liquidated damages. Second, we have considered loss-averse players. There exists a plethora of game theoretical models on supply chain contracting that use the principal agent framework, which has been reviewed in Section 2. Among these papers, delivery risk has been considered in modeling by Giovanni (2020) and Tao et al. (2021). However, they did not address the problems associated with loss-averse players. On the other hand, Katok and Wu (2009), Wang and Webster (2007), Dubey et al. (2018), and Eeckhoudt et al. (2018) considered loss aversion, but did not address the problem of delivery risk. Li et al. (2016) is the only study to address the problem of delivery risk in the presence of loss-averse players. However, their model does not address the problem of process breach along with delivery risk, neither does it compare optimal penalty to associated liquidated damage. Our study filled this research gap by designing an efficient contract, addressing both kinds of plausible breaches in the presence of loss-averse players.

Applied research on modern supply chains underscores the importance of meeting multiple bottom lines (Agrawal & Singh 2020), which are often achieved through communication and mutual trust (Behl et al. 2020; Gupta, Singh & Mangla 2021). Our research shows that this objective can be achieved through an efficient contract.

SCOPE OF FUTURE RESEARCH

As a risk mitigation strategy, almost all contracts signed between the buyer and the supplier include a remedial clause for delay and non-performance. For example, non-performance in terms of the specifications leads to rejection of the order. Similarly, the indemnity clause is used to safeguard against future failure, and the risk and cost clause is used to address the issues of incompletion or delay in project delivery. These clauses either include a penalty imposed by the buyer, or rejection of the order. Although our model considers the penalties involved in such cases, it does not explicitly discuss the strategies used by supply chain managers to mitigate the supply risk because it is not within the scope of the present study. Future research may study the connection between the liquidated damage and remedial clauses.

In this paper, we have assumed that if the supplier follows a standard process, which is prevalent in the same or similar industry, there is no risk of incorrect delivery. However, it is possible to increase

the complexity of the model by accounting for such risks. An emerging area of research in behavioral operations management is the study of supply chains with members having fairness concerns. However, few papers have studied how fairness concerns of signatories may impact a contract. There is significant scope in examining how the zone of efficient contract is affected by the fairness concerns of the buyer, the supplier, or both.

It is also important to experimentally examine the results obtained in this paper. There exists little empirical research on the role of loss-aversion in supply chain contracting. In this paper, we have theoretically and numerically shown that the penalty required for an efficient contract does not need to be greater than the liquidated damage. Our work highlights the need for experimental investigations into loss-averse behavior in the context of supply chain contracting. Moreover, the sociological and behavioral factors underlying loss-aversion by supply chain partners should also be studied in related research.

CONCLUSION

In this paper, we have developed a theoretical model of supply chain contracting by considering two kinds of delivery risks, resulting from two different types of plausible breaches – a breach in the quality, and a breach in the process followed. The buyer and the supplier are loss-averse and are mutually aware of these two types of plausible breaches. An efficient contract requires different penalties for the different types of breaches. Our model identifies the limits on these penalties, such that the participation and incentive compatibility constraints of the buyer and the supplier are satisfied. Consequently, there exists a zone of values, which we referred to as the zone of efficient contract, that enables the penalties to ensure that the contract is efficient. With the help of a numerical example, we have demonstrated how this zone of efficient contract changes with changes in values of variables and have compared the limits of the penalties to the liquidated damage due to the breach. We show that the penalty does not need to be necessarily greater than the liquidated damage, for the contract to be efficient. This is an important and novel contribution to the literature. Below we highlight our contribution.

First, our paper is the first one to design an efficient contract, considering loss-aversion. As discussed in Section 2, the delivery risk is a well-researched area. The role of a penalty and/or liquidated damage in designing supply-chain contracts have been studied (Cachon & Zhang 2006; Lutze & Özer 2008; Mathur & Shah 2008; Gan et al., 2010). However, unlike in our model, most of these papers assume the signatories to be loss-neutral. There is no paper in supply-chain contracting that designed an efficient contract in the presence of loss-aversion.

Second, we have compared the optimal penalties with the corresponding liquidated damages, and our numerical analysis shows that the optimal penalties need not be excessive compared to the liquidated damages. This finding is contrary to the general wisdom of legal literature, which presumes that penalties designed for the prevention of a breach are excessive compared to the liquidated damages.

Last, but not the least, our model is an early attempt in designing an efficient contract for a buyer who is concerned not only with the quality of the delivery but also about the process used in production. Considering two plausible breaches, i.e., a breach in the quality of the delivery, and a breach in the process, we have determined the combinations of penalties that satisfy the supplier's participation and incentive compatibility constraints.

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