Managing Reputation Risk in Supply Chains: The Role of Risk-sharing under Limited Liability

Vibhuti Dhingra and Harish Krishnan

UBC Sauder School of Business, Vancouver BC V6T 1Z2, Canada

vibhuti.dhingra@sauder.ubc.ca and harish.krishnan@sauder.ubc.ca

Abstract

When a supplier fails to comply with social and environmental standards, the buyer's reputation suffers. Reputation costs can typically be very high for the buyer whereas the supplier's liability is often limited. Conventional procurement strategies like dual sourcing mitigate the buyer's operational risk, but often do so at the expense of increasing its reputation risk and sourcing costs. In this paper, we propose a risk-sharing contract for managing the buyer's reputation concerns. We find that by sharing some of the supplier's operational loss, the buyer may (in some conditions) decrease its reputational risk but this has to be balanced against an increase in the operational risk. Risk-sharing also reduces sourcing costs because the buyer takes on some of the worst-case loss of a wealth-constrained supplier. These results suggest that risk-sharing can be superior, as a procurement strategy, to conventional approaches like dual sourcing or penalty contracts. This is true when reputation and sourcing costs are a significant concern, and operational costs are not that high. Under some conditions, the buyer may choose risk-sharing even if it increases reputation risk in order to reduce procurement costs.

Keywords: contracts and incentives; risk management; social responsibility in supply chains

1 Introduction

Multinationals are increasingly facing "reputation risk" due to their suppliers' actions which may violate the buyer's social and environmental standards. This risk, which is amplified due to NGO activism and the instantaneous reach of social media, can lead to severe financial implications in the form of consumer boycott of products, impact on brand image, litigation and regulatory intervention, or decline in stock prices and loss of market capitalization. According to a survey by Deloitte (2014), 87% of company executives reported reputation risk as their topmost strategic risk.

Suppliers can have at least two types of motives for committing social and environmental responsibility violations. One is to reduce production costs and the other is to mitigate operational risk. Consider, for example, the use of antibiotics in livestock farming. Meat producers sometimes administer antibiotics to livestock for non-therapeutic reasons such as disease prevention and growth promotion. Using antibiotics allows farmers to both (i) reduce their operational risk of having a low yield, and (ii) reduce their cost of production as animals on antibiotics typically consume less feed to reach the desired weight. In this paper, we primarily focus on the supplier's risk mitigation actions that could have a negative externality on the buyer. But in Section 7.2, we consider an extension to include the impact of supplier actions that are motivated by both risk and cost reduction goals.

Livestock are often reared in conditions which make them susceptible to diseases without the use of antibiotics. Disease outbreaks can cause significant losses. The H1N1 outbreak, for instance, cost US farmers $30-$35 per pig and global pork trade declined by 11% (Bloomberg, 2009). As a result, antibiotics use is common in meat production with farm animals receiving approximately 80% of antibiotics used in the US. Many of these antibiotics are deemed important for human health.

Moreover, the use of growth-promoting antibiotics has been a factor in allowing farmers to increase yields (Wegener et al., 1999). For instance, broiler chickens today reach an average slaughter weight of 6.18 pounds within 47 days of being hatched whereas in 1935 an average broiler chicken in the US took 98 days to attain a slaughter weight of 2.86 pounds (National Chicken Council, 2017).

A consequence of farm antibiotics use is that it can accelerate the development of resistant bacteria in the animals. When humans are exposed to resistant bacteria through contaminated food or environment, they can get drug-resistant infections.

Restaurant chains such as KFC and McDonald's, that source meat raised with antibiotics from these farms, have been facing backlash from consumers, governments, and NGOs alike. For instance, in 2016, five prominent consumer groups graded 25 US fast food restaurant chains on the antibiotics practices of their suppliers, with the goal of identifying the worst offenders (NRDC et al., 2016).

Policymakers are also tightening regulations to safeguard against the growing threat of antimicrobial resistance. For example, recent FDA guidelines mandate veterinary prescription for certain medically important antibiotics that were previously available over-the-counter (Bjerga, 2016). Another example is the 1998 ban in Denmark on the use of some antibiotics in farm animals. Industry research indicates that a similar ban in the US would cost $4.50 per animal during the first year of implementation and the industry could suffer a loss of approximately $700 million over a 10-year period at 2003 prices (FAIRR, 2016).

Resolving the issue of supplier responsibility is challenging for these multinational food companies because they face a twin threat. On one hand, they are exposed to additional costs if the supplier's operational risk is increased. For example, consider the situation where a meat supplier loses output to a flu outbreak. The retail chain sourcing from this supplier will then have to incur the costs of finding alternative sources of supply or restructuring its menu. Accordingly, the firm benefits if its supplier takes effort to mitigate operational risk. But, on the other hand, if the supplier's approach to risk mitigation involves transgressions such as compromising animal welfare or the excessive use of antibiotics, it faces pressure from stakeholders and a heightened reputation risk. Firms can hedge against operational risk by sourcing from multiple suppliers or by improving order fulfillment reliability (Wang et al., 2010). But we show in Section 7.1 that under reputation risk, diversifying the supply base can be inefficient for the buyer as it is held accountable for the wrongdoings of every supplier.

The challenge for a multinational, therefore, is to incentivize its suppliers to mitigate operational risk in a manner that circumvents any reputational repercussions down the road. To capture this trade-off, we assume the supplier's risk mitigation effort to be multidimensional i.e., it can be "bad" (e.g., excessive use of antibiotics) or "good" (e.g., process improvements).[1] Both efforts reduce operational risk in the supply chain, but only bad effort increases reputation risk. The goal for a multinational concerned about reputation impact, therefore, is to reduce bad effort and increase good effort in the supply chain. This trade-off between bad and good effort has not been looked at in existing studies, and it allows us to better understand the forces leading to incentive misalignment in the supply chain. In this setting, we ask the following research questions. When a firm cannot directly observe its supplier's actions, what role do contracts and financial tools play in managing reputation risk? Specifically, can risk-sharing be an effective instrument for this purpose?[2] Risk-sharing can lower the incentives for exerting effort. But when the goal is indeed to suppress one kind of supplier action (i.e., bad effort) to mitigate operational risk, can the firm be better off by sharing its supplier's risk? Furthermore, how does risk-sharing compare with more standard approaches of mitigating reputation risk in the supply chain such as a penalty contract?

We find that risk-sharing can either decrease both bad and good effort by the supplier, or *increase* one effort while *reducing* the other. The different decisions of the suppliers may be shaped by various factors including the regulatory landscape in the country of origin. Consider, for example, the case of salmon supplier Cermaq which has operations in Chile, Canada, and Norway. In the third quarter of 2018, Cermaq Chile used 433 gAPI[3] antibiotics per tonne of salmon harvested, whereas its consumption was close to zero in Norway during the same time period (Cermaq Global, 2018). The company attributes its high antibiotics use in Chile to the lack of large-scale policy

[1]We use the terminology "good" and "bad" effort as a shorthand to simplify exposition. More precisely, these efforts reflect the responsible and irresponsible actions taken by the supplier to manage operational risk during production.

[2]By risk-sharing, we refer to contractual provisions that compensate suppliers for losses in adverse events.

[3]gAPI is a unit that measures the quantity of antibiotics used weighted by their environmental risk (see Global Aquaculture Performance Index (2011))

and research initiatives in the country for finding sustainable farming methods. This is particularly true for a lethal disease affecting Chilean salmon. Cermaq claims that no individual enterprise has the expertise or the financial capability to tackle this problem on its own. In Norway, on the other hand, strong public-private partnerships and intense research programs have developed vaccines and other sustainable techniques for managing fish health, which has enabled their salmon producers to sharply curtail dependence on antibiotics (Einen, 2013).

The above discussion indicates that a supplier (such as the salmon producer based in Chile) who operates in a weakly regulated industry with less advanced manufacturing systems may gravitate towards bad effort to manage operational risk, rather than good effort, when the potential loss is huge. But if this operational loss is reduced through risk-sharing, the supplier may be persuaded to shift away from bad effort to using more good effort. On the other hand, a supplier (such as the salmon producer based in Norway) under a strong regulatory regime and with easy access to state-of-the-art production technology mitigates operational risk by choosing greater levels of good effort rather than bad effort. Reducing the loss for such a supplier through risk-sharing could instead serve as a perverse incentive to shift away from good effort to an increased level of bad effort.

So would the multinational firm benefit from sharing the supplier's risk? Clearly risk-sharing is advantageous in easing the buyer's reputation concerns when it increases good effort and decreases bad effort. Moreover, we find that it is useful even when both efforts decrease as long as reputation costs are high. But what about the case where risk-sharing increases bad effort and decreases good effort? It may then seem counter-intuitive for a firm to offer risk-sharing. But interestingly we find that, in this situation, a firm may use risk-sharing as a way to squeeze the margins of a wealth-constrained supplier. If the supplier has limited liability (ex-post) and must earn a non-negative profit under all conditions, the buyer has to set the contract payment high enough to cover the entire operational loss of the supplier. But by covering some of this loss (ex-ante) through risk-sharing, the buyer is able to negotiate a lower contract price. As a result, in this situation, even if risk-sharing were to increase noncompliance, it may be helpful for the buyer if the supplier's operational loss is high and the firm's reputation costs are relatively low.

Finally, we study how risk-sharing compares with a noncompliance penalty in addressing supplier responsibility issues. We find that such a penalty can sometimes be better at reducing *both* operational and reputation risk in the supply chain. But despite these lower risks under a penalty, we show that the buyer may prefer risk-sharing when reputation cost is low. The intuition again follows from the supplier's limited liability. When contracting with a wealth-constrained supplier, the buyer has to set the transfer payment sufficiently large so that the supplier does not incur a loss in the event the maximum penalty is charged. But in reality, the supplier only pays a penalty in expectation i.e., *if* reputation risk is realized. We show that this increase in contract price necessitated by a penalty may outweigh the benefits of reduced risks for the buyer, and make risk-sharing more attractive. In Section 6, we show that risk sharing can increase a buyer's profit substantially – by up to 300% in our experiments – relative to a wholesale price or a penalty contract.

Some prior studies, e.g. Chen and Lee (2017) and Babich and Tang (2012), have recommended a deferred payment mechanism as an alternative to penalty for resolving supplier responsibility issues. In this paper, we show that under limited liability, deferred payments provide no discernible advantage. This is because both the forfeiture amount and the penalty are capped when a wealth-constrained supplier's net equity reaches zero.

In summary, our work demonstrates an important role for risk-sharing in managing reputation risk that, to the best of our knowledge, has been ignored by researchers and practitioners alike. Moreover, we show that in settings where agents perform multiple tasks, an offer of risk-sharing can have non-trivial implications. Our results indicate that contractual incentives must be designed after carefully examining the trade-offs between reputational, operational, and transaction costs.

2 Related literature

This paper lies at the intersection of the literature on environmental and social responsibility in supply chains, and risk-sharing and performance-based contracts in operations management.

(1) Environmental and social responsibility in supply chains: Ensuring supply chain social and environmental responsibility has become an increasingly vexing issue for firms who are unable to observe and control the actions of far-flung suppliers. A vast majority of papers in the supply chain literature focus on resolving supplier responsibility issues through screening and monitoring mechanisms. Some examples include Guo et al. (2016), who study the supplier selection problem when consumers are socially conscious; Chen et al. (2019a), Fang and Cho (2015), and Caro et al. (2018), who study supplier audits in different multi-firm settings; Chen and Lee (2017) who look at the interaction between audits, certification, and contingency payment; and Cho et al. (2019) who examine the interplay between inspection and wholesale price to combat child labor.

But in recent years, researchers have questioned the efficacy of these mechanisms. For example, Plambeck and Taylor (2016) argue that audits may incentivize a supplier to hide violations instead of raising responsibility level. Short et al. (2016) and Chen et al. (2019b) find that collusion between the supplier and third-party inspectors can compromise the integrity of audit and certification results, respectively. Other researchers seek to address responsibility concerns by improving supply chain visibility and information disclosure (e.g., Kraft et al. (2017), Chen et al. (2019c), and Kalkanci and Plambeck (2019)); vertical integration (Orsdemir et al., 2019); imposing penalties on firms sourcing from unethical suppliers (Zhang et al., 2019); and designing a dynamic mechanism for supplier responsibility guidelines (Lewis et al., 2019). While approaches such as centralizing production and increasing transparency are certainly helpful, they may not always be practical solutions for firms with globally dispersed supply chains that reap significant economic benefits from off-shore manufacturing. These results point to the need for further research on how multinationals should manage the risk posed by supplier irresponsibility.

The role of contractual incentives and financial instruments in managing social responsibility has received very limited attention in this burgeoning literature. Our paper contributes to filling this gap by considering a risk-sharing contract offered to the supplier with the intent of mitigating the buyer's reputation risk. Unlike the aforementioned papers, we largely focus on the setting where a supplier's violations can reduce operational risk rather than production cost. Further, we assume the supplier's risk mitigation effort to be multidimensional. In the context of audits, Plambeck and Taylor (2016) also consider two types of efforts by the supplier: a responsibility effort to ensure worker and environmental safety, and a hiding effort to conceal violations. But the efforts in their model are chosen sequentially - only when the facility is unsafe can the supplier choose a hiding effort. On the other hand, in our model the supplier chooses bad and good effort simultaneously, and both the efforts serve the same purpose of reducing operational risk. Moreover, in their model, when the supplier chooses a hiding effort, both the buyer and the supplier incur damages but in our model the reputation damage from bad effort accrues only to the buyer.

(2) Risk-sharing and performance-based contracts: Risk-sharing contracts have been studied in the OM literature to protect against spot price uncertainties (Li and Kouvelis, 1999), to manage downside risk for a risk-averse retailer (Gan et al., 2005), to improve after-sales services (Kim et al., 2007), and to resolve double marginalization in a newsvendor setting (Chen et al., 2016). In contrast, we consider risk-sharing by the buyer to address reputational issues caused by the supplier's moral hazard. Similar to us, Plambeck and Zenios (2003) consider the problem of optimal risk-sharing in a principal-agent framework, where the supplier's action is hidden from the buyer. Our paper differs from their work in three fundamental ways. First, they consider an inventory control problem in make-to-stock production systems, whereas we focus on reputational concerns in supply chains. Second, they model agency problems in a dynamic setting whereas we have a single-shot model. And lastly, they consider a risk-averse agent while our paper models a risk-neutral supplier with limited liability.

Many researchers have also looked at risk-sharing through the lens of an insurance provision. In the OM literature, for example, Dong and Tomlin (2012) study the interaction between business interruption insurance and operational strategies to mitigate disruption risk for a single firm. But unlike their model, we consider risk-sharing as an instrument to mitigate reputation risk for the buyer in a multi-firm setting. Insurance contracts under moral hazard have also been extensively studied in the economics literature (see Winter (2000) for a comprehensive review). Within this broad stream of research, our work is most closely related to Tommasi and Weinschelbaum (2007) and Serpa and Krishnan (2017). Tommasi and Weinschelbaum (2007) consider moral hazard by a risk-averse agent who has access to insurance, whereas Serpa and Krishnan (2017) consider double-sided moral hazard with risk-neutral players and insurance provisions for the principal. In contrast, our model considers risk-neutral players and moral hazard on part of an agent whose risk is shared by the principal. Further, the aforementioned papers consider third-party insurance schemes, but in our model risk coverage is embedded in the contract offered to the agent.

As this paper is motivated by reputation risk in food supply chains, our work also contributes to the literature in agricultural economics. This research stream predominantly considers insurance as a mechanism through which public sector organizations can improve farm welfare. To encourage farm participation, premiums under government-sponsored insurance are either heavily subsidized or not collected at all. Because of this reason, the papers in this literature, such as Annan and Schlenker (2015) and Hennessey (2007), find that insurance exacerbates moral hazard and increases losses for the provider. On the contrary, in our model, we show that a firm can benefit from a risk-sharing provision either through reduced reputation risk or by a decrease in transfer payment.

Finally, we contribute to the broader literature on performance-based contracts (PBC) in principal-agent models. Prior studies in OM have considered PBC to improve product reliability in after-sales support (see, for example, Kim et al. (2007), Kim et al. (2010), and Bakshi et al. (2015)). Our paper is most closely related to Kim et al. (2007). Similar to bad and good effort in our model, Kim et al. (2007) also consider two types of actions by the agent. Specifically, in their model, the supplier chooses (i) a cost-reduction effort, and (i) the spare parts inventory level. Increasing spare parts inventory improves product availability but leads to higher total costs, whereas the supplier's cost-reduction effort has no impact on product availability. In other words, these two supplier actions are in direct conflict with each other. By contrast in our model, the supplier's bad and good effort are strategic substitutes and *both* reduce operational risk in the supply chain. Further, they consider multiple risk-averse agents whereas we study a single risk-neutral agent with limited liability. More importantly, their focus is on improving after-sales service of capital-intensive products, while we are interested in managing reputational issues in supply chains.

3 Model preliminaries

Consider a stylized model where a large risk-neutral multinational firm, M, procures one unit of an intermediate good (such as animal products) from a small risk-neutral supplier, S. The firm then sells the final product (such as restaurant meals) to the consumers in the market.

3.1 Supplier's investment and risk

To begin the production process, the supplier makes a fixed investment $K > 0$. This includes costs associated with the purchase of raw materials, hiring labor, and other miscellaneous expenses. The supplier can incur unforeseen losses in the course of production. For example, a farmer could end up with a low yield due to factors such as adverse weather events, equipment failure, or livestock diseases and pests. We refer to this as "operational risk." To reduce operational risk, the supplier can take costly effort which is unobservable to the buyer. We assume this effort to be multidimensional: it can be "good" or "bad." Good effort includes, for example, process improvements and machine maintenance, or improved housing and selective breeding of flocks in poultry production. Bad effort can involve the use of harmful inputs such as pesticides and antibiotics in farming.

We assume that the supplier's effort decisions are driven by their relative ease of implementation. For example, it may be easier and cheaper for a farmer to obtain pesticides and antibiotics than to look for and experiment with sustainable alternatives such as probiotics or invest in process improvements. An important characteristic of bad effort is that it may not necessarily impact the perceived quality of the manufactured good but can be harmful for the environment. For example, consumers usually cannot identify if their produce was sprayed with pesticides, but pesticide misuse in farming can contribute to soil degradation and water pollution. We focus on such "soft quality" problems (Chen and Lee, 2017) that, if disclosed, can tarnish the reputation of the buying firm.

Let $e_b \geq 0$ and $e_g \geq 0$ denote the bad and good effort exerted by the supplier, respectively where e_b and e_g represent the dollar value of the two efforts. Note that although their costs can be expressed in dollars, the efforts are not contractible i.e., the buyer cannot specify the level of efforts to be taken by the supplier. An operational loss, $X_S > 0$, occurs with probability $F_S(e_b, e_g) \in [0, 1]$. Operational loss includes, for instance, the cost of culling a flock of chickens due to disease. We assume that the operational risk function, $F_S(e_b, e_g)$, is twice differentiable, jointly convex, and decreasing in e_b and e_g. We further assume that $F_S(e_b, e_g)$ has increasing differences in (e_b, e_g) i.e., as good effort increases, the marginal decrease in risk (the absolute value of the risk reduction) due to bad effort decreases. Efforts are also substitutable in the sense that the supplier can exert more good effort in situations where it is difficult to exert bad effort and vice versa. Further, any difference between the cost of bad and good effort is captured through the operational risk function. Good effort is relatively more expensive if, for example, spending a large amount on organic farming leads to a very small reduction in yield risk. Moreover, our results are easily extended when the cost of efforts are $k_1 e_b$ and $k_2 e_g$ for $k_1, k_2 > 0$.

3.2 Multinational firm's risks

The multinational firm sells the final product in the market for a revenue of V. The supplier's actions affect the firm in two ways. First, the firm faces an operational loss with the same probability as the supplier i.e., $F_S(e_b, e_g)$. However, the value of the operational loss can be different for the multinational, and is denoted by $X_M > 0$. To see why, consider the case of the avian flu outbreak in 2015 which led to an egg shortage across the US and increased the wholesale price of chicken eggs by 84.5% (The Guardian, 2015). Food companies facing supply disruptions had to take costly contingent actions at the time. For example, McDonald's lined up alternative suppliers and the restaurant chain Whataburger cut back on breakfast hours (Strom, 2015; Fitzpatrick, 2015).

Second, the multinational faces a "reputation risk" if the supplier exerts bad effort.[4] Let R_M denote the reputation loss that occurs with probability $F_M(e_b) \in [0, 1]$. We assume that the reputation risk function, $F_M(e_b)$, is twice differentiable, increasing, and concave. This means that higher bad effort by the supplier leads to a higher reputation risk, and that the marginal increase in reputation risk decreases as bad effort increases. If the supplier makes no bad effort, the firm faces no reputation risk. We also assume that good effort has no impact on reputation risk.

If the multinational firm and the supplier are organized as a single entity, the supply chain benefits from increasing good effort and reducing bad effort when reputation cost increases. This is because good effort allows the centralized firm to reduce operational risk without inflicting any harm on its reputation.[5] In reality, however, decision-making is typically decentralized where suppliers

[4] In reality, a buyer's reputation risk depends not only on the supplier's actions but also on the probability with which violations are revealed to the public. The level of scrutiny by government and NGOs determines the likelihood of public disclosure. While we do not model the role of external stakeholders, there will be no qualitative change in our results by including a constant multiple in the reputation risk function that represents the probability of violation detection. This accords with other papers in the literature (e.g., Huang et al. (2017); Chen and Lee (2017)) that assume detection probability to be exogenous.

[5] We provide a formal analysis for the benchmark model in Appendix B.1.

take self-interested actions that are unobservable to the buying firm, leading to a principal-agent problem with moral hazard. We study this problem in the following sections.

3.3 Decentralized supply chain: Wholesale price contract

We model the following setting. First, the multinational firm offers a "take-it-or-leave-it" contract to the supplier, who is a small wealth-constrained firm with zero ex-post liability. Ex-post limited liability ensures that in the event of bankruptcy, the supplier cannot be forced to incur additional losses due to contractual obligations (Sappington, 1983). This is reasonable for a cash-strapped supplier who may renege on the contract if the transfer payment is too low. The supplier decides whether or not to accept the offer based on its expected payoff. Once the contract is accepted, the supplier exerts bad and good effort to mitigate operational risk. Finally, the buying firm incurs an expected reputation loss which depends on the supplier's chosen level of bad effort.[6]

We first consider a contract that includes an offer of a fixed transfer payment of $T > 0$ to the supplier. The total order quantity is assumed to be one unit. This type of contract is commonly observed in practice, particularly in the agriculture sector. Such a contract can be beneficial for both the farmer and the food companies. Advantages for farmers include protection from crop price volatility and difficulty in finding buyers on commodity spot markets. The buying firm can also benefit by specifying input requirements (such as use of certified seed providers) to the farmer. As Federgruen et al. (2019) state, such restrictions "can be built into a contract, but, on the spot market, it is very hard to find (sufficient) suppliers that conform with them."

If the supplier accepts the contractual agreement, production begins in the next stage. The supplier then makes a fixed investment (K) and chooses efforts (e_b and e_g) to reduce the risk ($F_S(e_b, e_g)$) of operational loss (X_S). Let e_b^w and e_g^w represent the supplier's optimal bad and good effort under wholesale price contract, respectively. Then, the multinational firm chooses the transfer payment to minimize its operational and reputation risk subject to the supplier's ex-post limited liability. The firm's problem is formulated as follows.

[6]Note that the buyer never observes the actual efforts taken by the supplier, and only observes the *outcomes* of those efforts ex-post. More importantly, this outcome is a *noisy* or an imperfect signal of effort. That is, the buyer cannot deduce the supplier's effort decisions by observing the outcome (see, for example, Bolton and Dewatripont (2004) pp. 129, and Mas-Colell et al. (1995) pp. 478-479).

$$\begin{aligned}
\max_{T\geq 0} E\Pi_M \quad &= \quad V - T - F_S(e_b^w, e_g^w)X_M - F_M(e_b^w)R_M \\
\text{subject to} \quad & \quad T - X_S - K - e_g^w - e_b^w \ \geq 0 \\
& \quad T - F_S(e_b^w, e_g^w)X_S - K - e_g^w - e_b^w \ \geq 0 \\
& \quad (e_b^w, e_g^w) \in \arg\max_{e_b, e_g \geq 0} T - F_S(e_b, e_g)X_S - K - e_g - e_b \\
& \quad E\Pi_M \geq 0
\end{aligned}$$

The first two constraints represent the supplier's (ex-post) limited liability and individual rationality constraints, respectively. The third constraint represents the supplier's incentive-compatibility constraint i.e., the supplier chooses profit-maximizing levels of efforts. We assume that the market price, V, is large enough for the multinational to enter the business i.e., the last constraint is satisfied. Let T^* denote the optimal transfer price. The supplier's participation constraint is non-binding and can be removed (because if it were binding, limited liability constraint would be violated). At optimality, the limited liability constraint binds because if it were not binding, the firm could increase profits by reducing the supplier's transfer payment without violating any constraints.

Given this setup, we compare the supplier's efforts under a wholesale price contract with the efforts of the centralized firm (denoted by e_b^c and e_g^c).

Proposition 1. *If* $\frac{dF_M(e_b)}{de_b} > -\frac{X_M}{R_M}\frac{\partial F_S(e_b,e_g)}{\partial e_b}$, *then* $e_b^w > e_b^c$ *and* $e_g^w < e_g^c$.

Proof. All proofs are in the online appendix. □

When the marginal increase in reputation risk is above a certain threshold, the supplier exerts more bad effort and lower good effort than the centralized firm. Moreover this threshold is lowered when R_M increases or X_M decreases which, in turn, makes it more likely that the supplier exerts greater bad effort and lower good effort than the centralized firm. This result is not surprising as the supplier does not incur any reputation loss and a fixed-price contract also provides no incentive to curtail bad effort. Consequently, the supplier's effort decisions are determined solely by their impact on the operational risk function.

Therefore, a multinational concerned about its reputation, will need to redesign the contractual terms to reduce bad effort by the supplier. We explore two mechanisms for managing the buyer's reputation risk: a risk-sharing contract (Section 4) and a penalty contract (Section 5).

4 Risk-sharing contract

In this section, we propose a risk-sharing contract between the multinational firm and its supplier to manage reputation risk. We are interested in risk-sharing because it typically reduces an agent's incentives to exert effort, and in this context, reducing the supplier's bad effort leads to a lower reputation risk for the buyer. We consider the following contract. The multinational firm offers a fixed transfer payment, $T > 0$, to the supplier along with an offer to absorb a fixed share, $\delta \in [0, 1)$, of the supplier's operational loss, X_S.[7]

Under this contract, the supplier makes a fixed investment, K, and chooses efforts, e_b and e_g, to minimize the risk of operational loss, $(1 - \delta)X_S$. The remainder of the operational loss, δX_S, is borne by the multinational firm. Let e_b^r and e_g^r represent the supplier's optimal bad and good effort under a risk-sharing contract. Then, the multinational firm chooses the transfer payment and the coverage level to minimize its operational and reputation risk, and solves the following.

$$\begin{aligned}
\max_{T\geq 0, \delta\in[0,1)} E\Pi_M \quad &= \quad V - T - F_S(e_b^r, e_g^r)(X_M + \delta X_S) - F_M(e_b^r)R_M \\
\text{subject to} \quad & \quad T - (1-\delta)X_S - K - e_g^r - e_b^r \geq 0 \\
& \quad T - F_S(e_b^r, e_g^r)(1-\delta)X_S - K - e_g^r - e_b^r \geq 0 \\
& \quad (e_b^r, e_g^r) \in \arg\max_{e_b, e_g \geq 0} T - F_S(e_b, e_g)(1-\delta)X_S - K - e_b - e_g \\
& \quad E\Pi_M \geq 0
\end{aligned}$$

Let (T^*, δ^*) denote the optimal solution to the above problem. As in the case of the wholesale price contract, the limited liability constraint binds at optimality and we can remove the participation constraint as it is non-binding. Note, however, that risk-sharing makes the limited liability constraint weaker for the firm as it now has to pay the supplier only $(1-\delta)X_S$ instead of X_S. Now the question is how risk-sharing changes the supplier's effort choices. From here on, we restrict our attention to the interesting case where the supplier is actively choosing between bad and good effort i.e., neither effort is zero.[8] To guarantee interior solutions, we have the following lemma.

Lemma 1. *If* $\lim_{e_b\to 0} \frac{\partial F_S(e_b,e_g)}{\partial e_b} < \lim_{e_b\to 0} \frac{\partial F_S(e_b,e_g)}{\partial e_g}$ *and* $\lim_{e_g\to 0} \frac{\partial F_S(e_b,e_g)}{\partial e_b} > \lim_{e_g\to 0} \frac{\partial F_S(e_b,e_g)}{\partial e_g}$*, then* $e_b^r > 0$ *and* $e_g^r > 0$.

Intuitively, the above condition means that good effort is relatively less effective at reducing

[7] If $\delta \geq 1$, the supplier *benefits* from increasing operational risk which is not realistic. On the other hand, $\delta < 0$ is equivalent to imposing a penalty on the supplier if operational risk materializes, and our results are easily extended to this case.

[8] It is worth noting that the supplier's profit decreases in bad effort when it receives near-full risk-coverage, i.e., $e_b = 0$ if $\delta \to 1$. While this is a socially optimal outcome, it is not necessarily preferable for the buyer since it has to balance *both* operational and reputation costs.

operational risk at low levels of bad effort, and vice versa. For this reason, the supplier would optimally choose to not exert zero levels of an effort.

To understand how risk-sharing alters efforts, note that a supplier's trade-offs between bad and good effort are often governed by institutional factors beyond its control such as resource availability, environmental conditions, and regulatory framework where it is based. As a result, two suppliers in the same industry selling to the same retailer can have entirely different risk mitigation strategies.

For instance, a supplier in a developing economy may not have easy access to advanced manufacturing systems and may be unlikely to face severe consequences of any violation due to weak regulatory enforcement. Such a supplier may gravitate towards bad effort to manage operational risk rather than good effort when the potential loss due to operational risk is enormous. But if this loss is reduced through risk-sharing, the supplier may be persuaded to shift away from bad effort to using more good effort. On the other hand, a supplier in a developed country is more likely to have access to state-of-the-art production technology and will also be under stringent public and government scrutiny if any violations were discovered. We can, therefore, expect such a supplier to mitigate operational risk by choosing greater levels of good effort rather than bad effort. Reducing the loss for such a supplier through risk-sharing could instead serve as a perverse incentive to shift away from good effort to an increased level of bad effort.

One example in practice where we observe such a dichotomy is salmon farming. Norway and Chile are two of the largest salmon producers in the world. In 2013, Norway produced 1.3 million tonnes of fish using only 972 kilos of antibiotics. By contrast that same year, Chile produced 750,000 tonnes of salmon using more than 450,000 kilos of antibiotics. And in 2014, Chilean salmon farms increased their consumption of antibiotics by 25% to 563,200 kilos for producing 895,000 tonnes of fish (Financial Times, 2016). What factors contribute to this disparity?

We first discuss Norway which has a number of regulations in place to limit farm antibiotics usage by its salmon industry. These include prohibiting their routine use for disease prevention, requiring farms to document and register all usage with the government, eliminating economic incentives for veterinarians to prescribe them, and reserving certain classes of antibiotics exclusively for the treatment of humans (Terazono, 2017). In contrast, salmon farming in Chile is a weakly regulated industry that has allowed multiple fish farms to mushroom within close proximity causing substantial water pollution. Water pollution, in turn, has spurred the occurrence and transmission of diseases among the fish. In addition, the country has not been able to develop a vaccine for one of the deadliest bacteria crippling its salmon industry (Esposito, 2015).

A supplier such as the Chilean farmer may heavily lean towards bad effort rather than good effort when the potential loss due to operational risk is large. But if this loss is reduced through risk-sharing, the supplier may be persuaded to shift away from bad effort to using more good effort. On the other hand, a supplier such as a Norwegian salmon producer, inclines towards more good effort than bad effort when the operational loss is high. Reducing the loss for such a supplier through risk-sharing could instead be a pernicious incentive to shift away from good effort to an increased level of bad effort. When the supplier is not in one of these two extreme scenarios, reducing operational loss through risk-sharing has the expected outcome of suppressing both bad and good effort. The proposition below summarizes the above discussion.

Proposition 2. *Let MRS* $= \frac{\partial F_s(e_b,e_g)}{\partial e_b} / \frac{\partial F_s(e_b,e_g)}{\partial e_g} > 0$ *represent the slope of the indifference curve for the operational risk function,* $F_S(e_b, e_g)$*. Define* $\Theta_1 = \frac{\partial^2 F_S(e_b,e_g)}{\partial e_b \partial e_g} / \frac{\partial^2 F_S(e_b,e_g)}{\partial e_g^2} > 0$ *and* $\Theta_2 = \frac{\partial^2 F_S(e_b,e_g)}{\partial e_b^2} / \frac{\partial^2 F_S(e_b,e_g)}{\partial e_b \partial e_g} > 0$*. Then the relationship between supplier's optimal efforts under wholesale price contract and risk-sharing contract is characterized as follows.*

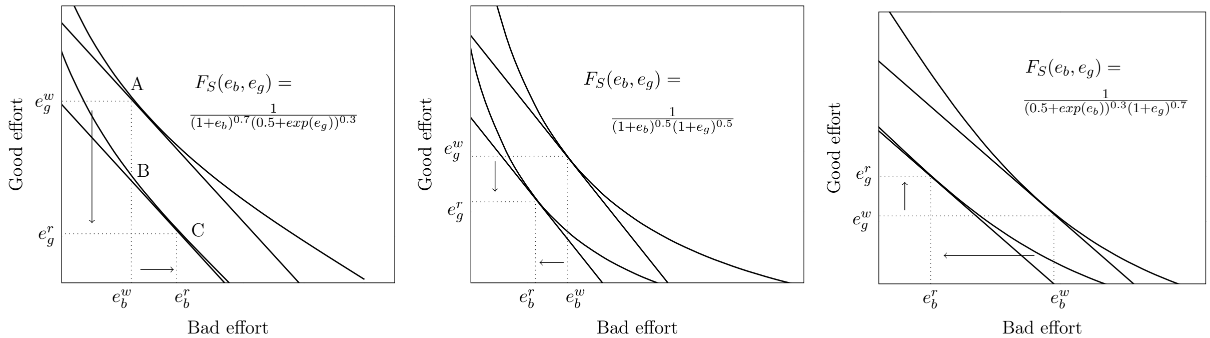
(i) $e_b^w + e_g^w > e_b^r + e_g^r$*, and*

(ii)
$$\begin{cases} e_b^w < e_b^r \text{ and } e_g^w > e_g^r, & \text{if } MRS \leq \Theta_1 \\ e_b^w > e_b^r \text{ and } e_g^w > e_g^r, & \text{if } MRS \in (\Theta_1, \Theta_2) \\ e_b^w > e_b^r \text{ and } e_g^w < e_g^r, & \text{if } MRS \geq \Theta_2 \end{cases}$$

Note first, from Proposition 2(i), that risk-sharing always suppresses total effort by the supplier (i.e., the sum of bad and good effort) as the overall incentive for risk mitigation is reduced by risk-sharing through lower operational loss for the supplier. Intuitively, we would expect that risk-sharing suppresses both bad and good effort. But as Proposition 2(ii) shows, this is true only when MRS is between the two thresholds Θ_1 and Θ_2. Interestingly, when MRS is high ($\geq \Theta_2$), risk-sharing not only suppresses bad effort but it also *increases* good effort. At the other extreme, for low MRS($\leq \Theta_1$), risk-sharing suppresses good effort while increasing bad effort.

So why does the impact of risk-sharing on efforts depend on the slope of the indifference curve? We start by considering the condition MRS $\leq \Theta_1$ which is equivalent to the slope decreasing in good effort.[9] This case corresponds to Figure 1a with the optimal efforts (under a wholesale price contract) given by point A where the indifference curve is tangent to the "budget line." This budget line represents the total expenditure on bad and good effort, and is implicitly determined by the solution to the supplier's problem.

[9]This is because MRS $\leq \Theta_1 \iff \frac{\partial^2 F_s}{\partial e_b \partial e_g} \frac{\partial F_s}{\partial e_g} - \frac{\partial F_s}{\partial e_b} \frac{\partial^2 F_s}{\partial e_g^2} \leq 0 \iff \frac{\partial}{\partial e_g} \left(\frac{\partial F_s}{\partial e_b} / \frac{\partial F_s}{\partial e_g} \right) \leq 0$ i.e., $\frac{\partial}{\partial e_g}$MRS ≤ 0.



(a) MRS $\leq \Theta_1$ (b) MRS $\in (\Theta_1, \Theta_2)$ (c) MRS $\geq \Theta_2$

Figure 1: Supplier's efforts under risk-sharing contract versus wholesale price contract

From Proposition 2(i), we know risk-sharing reduces total effort and shifts the budget line downwards. We argue that any point on the lower indifference curve that lies to the left of B cannot be the point of tangency for this new budget line. Suppose for a moment that B is the point of tangency. This implies that the slope of the indifference curve at B equals the slope of the curve at A (because A is the optimal point for wholesale price contract). But as slope is decreasing in good effort, the slope of the curve at B is in fact greater than the slope at A. Further, as the indifference curves are convex to the origin, any point to the left of B will have a higher slope than the slope at B. Hence, the point of tangency must lie to the right of B i.e., bad effort increases and good effort decreases with risk-sharing in this case. Similarly, we can show that MRS $\geq \Theta_2$ is equivalent to the slope increasing in bad effort, and MRS $\in (\Theta_1, \Theta_2)$ is equivalent to the slope decreasing in bad effort but increasing in good effort. Using arguments analogous to above, we find that risk-sharing increases good effort and reduces bad effort when MRS $\geq \Theta_2$, and that it decreases both bad and good effort when MRS $\in (\Theta_1, \Theta_2)$. Figure 1 illustrates each of these possibilities.

The above analysis shows that risk-sharing can reduce supplier violations in some cases, but may lead to unintended consequences in others.[10] A natural question to ask is if the multinational firm should offer a risk-sharing contract to the supplier, which we address in the following proposition.

Proposition 3. *There exists a threshold, $u(X_S, X_M, \delta)$, such that the multinational firm offers a strictly positive level of risk-coverage to the supplier if $F_M'(e_b^r)(\partial e_b^r/\partial\delta)\big|_{\delta=0} R_M < u(X_S, X_M, 0)$. The threshold is increasing in X_S and decreasing in X_M.*

The above result states that the firm's decision to offer risk-sharing depends on the relative trade-offs between the reputation loss and the operational losses in the supply chain. There are two

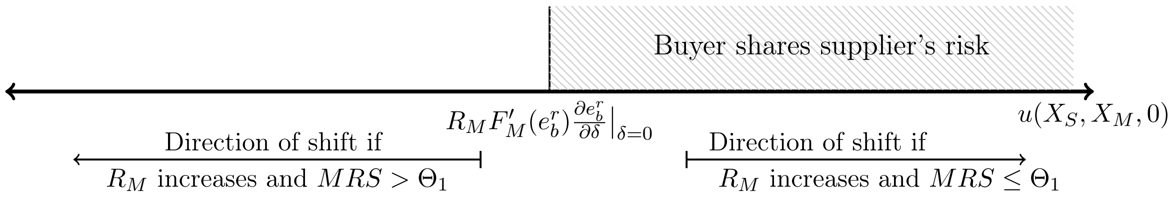
[10] In light of the discussion preceding Proposition 2, it is possible that Norway corresponds to MRS $\leq \Theta_1$ and Chile corresponds to MRS $\geq \Theta_2$. However, regulatory environments are complex and the conditions on MRS do not capture all their intricacies.

implications. The first is when risk-sharing reduces bad effort i.e., when $(\partial e_b^r/\partial\delta)\big|_{\delta=0} < 0$. Recall from Proposition 2 that this condition is equivalent to MRS $> \Theta_1$. Rearranging the terms in the above condition implies that R_M must be above a certain threshold for the firm to offer risk-sharing. In other words, the firm can strategically use risk-sharing to suppress supplier's bad effort when reputation costs are significantly high. Moreover, all else being equal, as reputation cost increases, the buyer is more likely to prefer risk-sharing when it decreases bad effort (see Figure 2a).

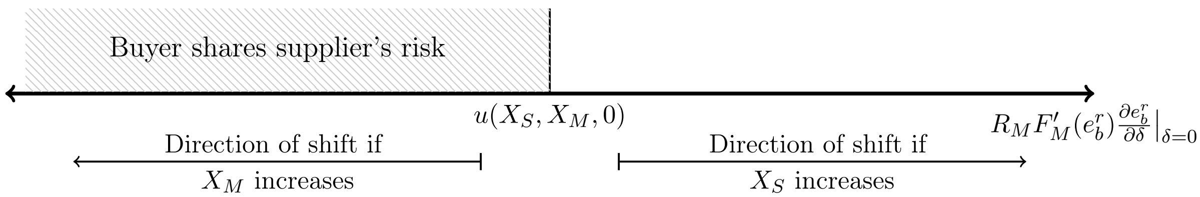
It is worth emphasizing here that not every firm would want to curb the supplier's bad effort through risk-sharing, but only the one for whom reputation is a critical asset. This may help explain why some retail firms such as GPA SA in Brazil prefer sourcing salmon from Chile despite antibiotics risk whereas firms in the US such as Costco, Walmart, and Whole Foods are shifting their demand from Chilean to Norwegian producers. In 2014, Chile's salmon exports had increased by 24% to $4.4 billion in spite of enormous antibiotics usage (Esposito, 2015). This is because some buyers such as those in Brazil operate in a market where concern about antibiotics misuse may be limited and sourcing costs are a bigger concern for firms rather than reputation impact.

The second possibility is when risk-sharing increases bad effort i.e., when $(\partial e_b^r/\partial\delta)\big|_{\delta=0} > 0$, or equivalently MRS $\leq \Theta_1$. The condition in the proposition will now imply that R_M must be small and that X_S must be large for the firm to offer risk-sharing. In this case, risk-sharing increases both operational risk (by decreasing total effort) and reputation risk (by increasing bad effort) for the buying firm. Why then would it still want to share the supplier's risk? The intuition is as follows. As the supplier's limited liability constraint binds at optimality, the firm has to pay the supplier enough to cover its entire operational loss. Recall that risk-sharing makes the limited liability constraint weaker and allows the firm to compensate the supplier for only a fraction of its operational loss. So when the supplier's operational loss is high and the firm's reputation loss is low; it can use risk-sharing (despite an increase in bad effort) to put a cap on the transfer payment to a wealth-constrained supplier. This suggests that even if risk-sharing worsens social welfare, it can be a useful asset for multinationals in managing their supply chain.

It is worth noting here that in the *absence* of limited liability, the buyer would never offer a risk-sharing contract if it were to increase violations. When the supplier can bear large losses, the optimal transfer payment has to satisfy only the individual rationality constraint. As a result, the "low payment" advantage of a risk-share agreement cancels out in the buyer's expected profit. So when bad effort increases, the buyer has no incentive to share the supplier's risk as both operational and reputation risk increase. A formal analysis for this result is presented in Section 7.3 where we consider a general level of net equity for the supplier.



(a) The value of risk-sharing as reputation cost increases.



(b) The value of risk-sharing as operational costs increase.

Figure 2: Buyer's decision to offer risk-sharing as a function of operational and reputation costs.

Further, all else being equal, the buyer is more likely to use risk-sharing when the supplier's operational loss, X_S, increases. Again, this is because the buyer can negotiate a lower transfer payment under limited liability through risk-sharing. On the other hand, the buyer's preference for risk-sharing reduces when (all else being equal) its own operational loss, X_M, increases. This is because risk-sharing increases operational risk, and a higher X_M will further raise the buyer's expected operational cost. See Figure 2b for an illustration.

So far, we have established that (1) risk-sharing can increase or decrease the supplier's bad effort, and that (2) it can be beneficial to the buyer in either scenario. The next question, then, is how much coverage should the buyer provide? We have the following result.

Proposition 4. *The bounds on the optimal coverage level, δ^*, are obtained as follows.* $\delta^* \leq \left(\frac{X_S - X_M}{2X_S}\right)^+$ *if $MRS \leq \Theta_1$ and $R_M \gg X_S$, and $\delta^* \geq \left(\frac{X_S - X_M}{2X_S}\right)^+$ if $MRS > \Theta_1$.*

Proposition 4 states that there is an upper bound on the optimal coverage offered by the buyer if risk-sharing increases bad effort and the buyer's reputation cost is *significantly* higher than the supplier's operational loss. In fact, this bound is less than 50%.[11] More importantly, in this case, the supplier receives zero coverage when the buyer's operational loss also exceeds the supplier's operational loss (i.e., $X_M > X_S$). This is because if risk-sharing increases bad effort, it is only beneficial to the buyer when X_S is reasonably large (due to a weakened limited liability constraint). But when X_S is small in comparison to both X_M and R_M, the buyer is better off without sharing

[11] To see why, observe that $\frac{X_S - X_M}{2X_S} < \frac{1}{2} \iff -2X_M < 0$ which is true as $X_M > 0$.

the supplier's risk. On the other hand, if risk-sharing decreases bad effort, there is a lower bound on the coverage level offered to the supplier. Moreover, this bound is strictly positive when $X_S > X_M$.[12] The intuition is as follows. When $MRS > \Theta_1$, risk-sharing has two benefits: (1) it reduces reputation risk, and (2) it reduces the transfer payment. The only drawback of risk-sharing, in this case, is that it increases operational risk which is not as important to the buyer when X_M is small.

5 The role of supplier penalty

The simplest way to reduce responsibility violations is to collect penalties from the supplier if risk materializes. In this section, we study the role played by penalties in managing the buyer's reputation risk, and compare it with a risk-sharing contract. Ideally, the multinational can transfer its costs to the supplier by imposing a penalty of X_M if operational risk materializes and R_M if reputation risk is realized. But as the supplier is protected by limited liability, this would require setting the contract payment high enough to cover the full amount of penalties. In other words, the supplier must receive a transfer payment of $T^* = X_S + X_M + R_M + K + e_b + e_g$. Thus, while theoretically possible, transferring entire reputation and operational losses to the supplier through penalties is impractical to achieve. This is particularly true when the buyer is a large multinational firm with significant reputation costs ($R_M \to \infty$).[13]

Nevertheless, penalties are another tool at the buyer's disposal and, under limited liability, can be used to salvage a part of the firm's reputation and operational costs from the supplier. Formally, suppose that in addition to a fixed transfer payment, the buyer imposes a penalty, $R_S > 0$, on the supplier if reputation risk materializes (which happens with probability $F_M(e_b)$).[14] Let e_g^p and e_b^p represent the supplier's optimal efforts under a penalty contract. We have the following result.

Proposition 5. *If* $\frac{dF_M(e_b)}{de_b}(R_M - R_S) > -X_M \frac{\partial F_S(e_b,e_g)}{\partial e_b}$, *then* $e_b^w > e_b^p > e_b^c$ *and* $e_g^w < e_g^p < e_g^c$.

A penalty contract reduces supplier's bad effort and increases good effort in comparison to a wholesale price contract. But it falls short of replicating the centralized efforts as long as the expected residual reputation cost incurred by the multinational firm exceeds a certain threshold. This is not surprising as the supplier is wealth constrained and hence does not bear the full costs of reputation damage. Specifically, the maximum penalty is capped when the supplier's net equity

[12] This is because $\frac{X_S - X_M}{2X_S} > 0 \iff X_S > X_M$.

[13] Moreover, if such a high penalty for reputation risk could be charged, the supplier would exert no bad effort because its profit would be decreasing in bad effort. That is, in the absence of limited liability, a penalty contract could yield a socially optimal outcome.

[14] We do not explicitly consider a penalty for operational risk as such a penalty can be subsumed in the supplier's operational loss, X_S.

reaches zero. This can be seen from the multinational firm's problem, which is given by

$$\begin{aligned}
\max_{T, R_S \geq 0} E\Pi_M &= V - T - F_S(e_b^p, e_g^p)X_M - F_M(e_b^p)(R_M - R_S) \\
\text{subject to} \quad & T - X_S - R_S - K - e_g^p - e_b^p \geq 0 \\
& T - F_S(e_b^p, e_g^p)X_S - F_M(e_b^p)R_S - K - e_g^p - e_b^p \geq 0 \\
& (e_b^p, e_g^p) \in \arg\max_{e_b, e_g \geq 0} T - F_S(e_b, e_g)X_S - F_M(e_b)R_S - K - e_b - e_g \\
& E\Pi_M \geq 0
\end{aligned}$$

Let (T^*, R_S^*) denote the solution to the above problem. The limited liability constraint needs to compensate the supplier in the worst case i.e., when it has to bear the reputation penalty. As this constraint binds at optimality, the maximum penalty is given by $R_S^* = T^* - X_S - K - e_g^p - e_b^p$. This result reiterates the reality of contracting with small suppliers, where buyers find it difficult to enforce harsh penalties (as also discussed in Chen and Lee (2017) and Plambeck and Taylor (2016)). This points to the need to consider additional instruments for managing reputation risk.

Some prior studies have proposed deferred payments as an alternative to penalties for addressing supplier violations. The rationale is that it may be easier for the buyer to withhold a part of the contract payment until any violations are discovered than to enforce a penalty on a far-flung supplier after a payment has been made. Babich and Tang (2012) and Rui and Lai (2015) focus on deferred payments to deal with material violations induced by supplier's moral hazard. On the other hand, Chen and Lee (2017) study a variant of deferred payment mechanism to address process violations occurring due to adverse selection. In Appendix B.2, we study the role of deferred payments to address process violations that may arise due to moral hazard. Unlike the previous papers, we consider the supplier to be a small firm that is constrained by limited liability and we show that this reduces the efficacy of a deferred payment mechanism in resolving supplier responsibility issues.

6 Risk sharing versus penalty contract

The above analysis shows that relative to a wholesale price contract, imposing a penalty on the supplier (i) reduces bad effort, (ii) increases good effort, and (iii) increases the transfer payment (due to limited liability). On the other hand, risk-sharing may increase or decrease the supplier's bad and good effort, and always decreases the transfer payment (as shown in Section 4). But how do these two contracts compare with each other? Is a penalty *always* more effective than risk-sharing at reducing supplier violations? Which contract should the multinational offer? In this section, we address these questions and complement our analytical findings with numerical experiments. We first characterize the supplier's efforts under the wholesale price, risk-sharing, and penalty contracts.

Proposition 6. *Define MRS, Θ_1, and Θ_2 as before. Then, the supplier's efforts under the three contracts; namely wholesale price, risk-sharing, and penalty; are ordered as follows.*

(i) $e_b^p + e_g^p > e_b^w + e_g^w > e_b^r + e_g^r$

(ii) $e_b^p < e_b^w < e_b^r$ *if* $MRS \leq \Theta_1$ *and* $e_g^p > e_g^w > e_g^r$ *if* $MRS \leq \Theta_2$

Corollary 1. *A penalty contract always leads to a lower operational risk than a risk-sharing contract, and a lower reputation risk if $MRS \leq \Theta_1$.*

We find that the sum of bad and good effort is always the highest under a penalty contract. When $MRS \leq \Theta_1$, penalty leads to the lowest bad effort and the highest good effort. When $MRS \in (\Theta_1, \Theta_2)$, good effort is still the highest under a penalty but bad effort may be greater or lower than risk-sharing and its magnitude will depend on the optimal values of risk-coverage and penalty chosen by the buyer. When $MRS > \Theta_2$, similar to a penalty, risk-sharing also reduces bad effort and increases good effort relative to the wholesale price contract (see Proposition 2(ii)). The ranking of efforts in this case will, therefore, depend on the optimal contract terms.

Interestingly, Corollary 1 shows that imposing a penalty for reputation risk also ends up reducing *operational risk*. In fact, operational risk is *always* the lowest under a penalty. This follows from the result (in Proposition 6(i)) that the total effort is the highest under a penalty. On the other hand, penalty leads to a lower reputation risk than risk-sharing if $MRS \leq \Theta_1$. For $MRS > \Theta_1$, reputation risk under a penalty contract may be greater or lower than that under risk-sharing. This is because when $MRS > \Theta_1$, both risk-sharing and penalty reduce bad effort, and the magnitude of decrease is determined by the optimal contract terms.

To summarize, penalty is better than risk-sharing for reducing both operational and reputation risk if $MRS \leq \Theta_1$. Then, should the buyer consider risk-sharing in this case? Recall that risk-sharing weakens the limited liability constraint as the multinational only has to pay the supplier $(1-\delta)X_S$ in the worst case instead of its entire operational loss, X_S. On the contrary, a penalty contract makes supplier's wealth constraint stronger by *increasing* the transfer payment. This is because the contract must now cover not only the entire operational loss, X_S, of the supplier but also the full amount of any penalty, R_S, that may be charged. This higher contract payment necessitated by a penalty under limited liability may outweigh the benefit of reduced bad effort for the buyer.

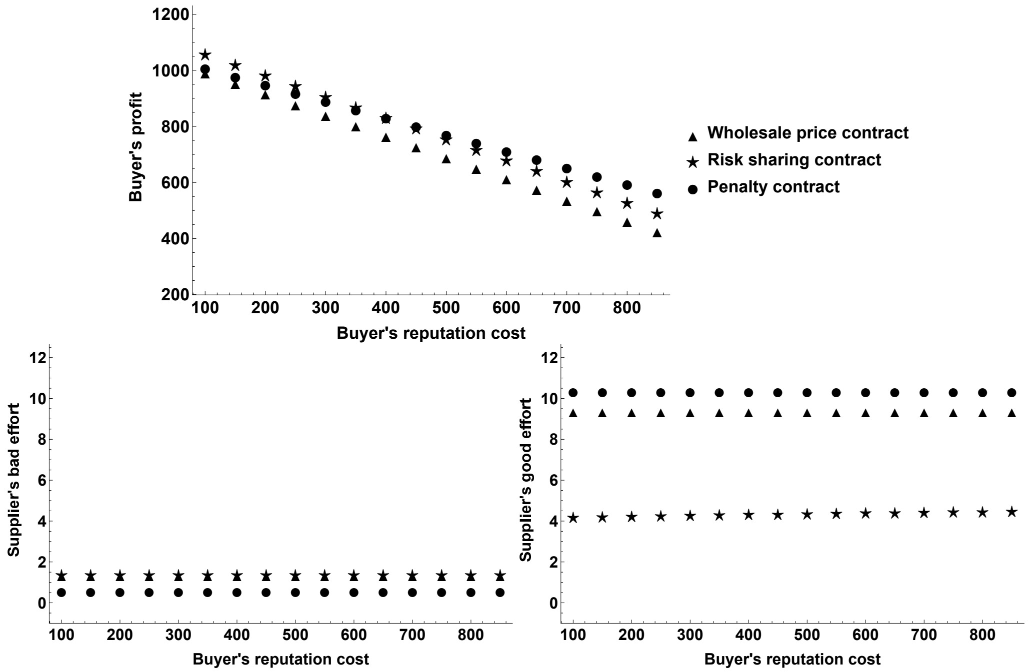
Formally, this can be seen by comparing the expected profit of the buyer under the two contracts. Let δ^* and R_S^* denote the optimal coverage level and penalty chosen by the buyer. Using the superscripts r and p for a risk-sharing and a penalty contract respectively, we have the maximal expected profits of the multinational firm under each case as follows.

$$\begin{aligned} E\Pi_M^r &= V-(1-\delta^*)X_S-K-e_b^r-e_g^r-(X_M+\delta^*X_S)F_S(e_b^r,e_g^r)-F_M(e_b^r)R_M \\ E\Pi_M^p &= V-X_S-R_S^*-K-e_b^p-e_g^p-F_S(e_b^p,e_g^p)X_M-F_M(e_b^p)(R_M-R_S^*) \end{aligned}$$

The buyer prefers risk-sharing contract over a penalty contract if and only if $\Delta = E\Pi_M^r - E\Pi_M^p \geq 0$. For ease of exposition, suppose that the buyer's operational loss $X_M = 0$. That is, the buyer only considers the tradeoff between its reputation cost and the supplier's transfer payment. Then,

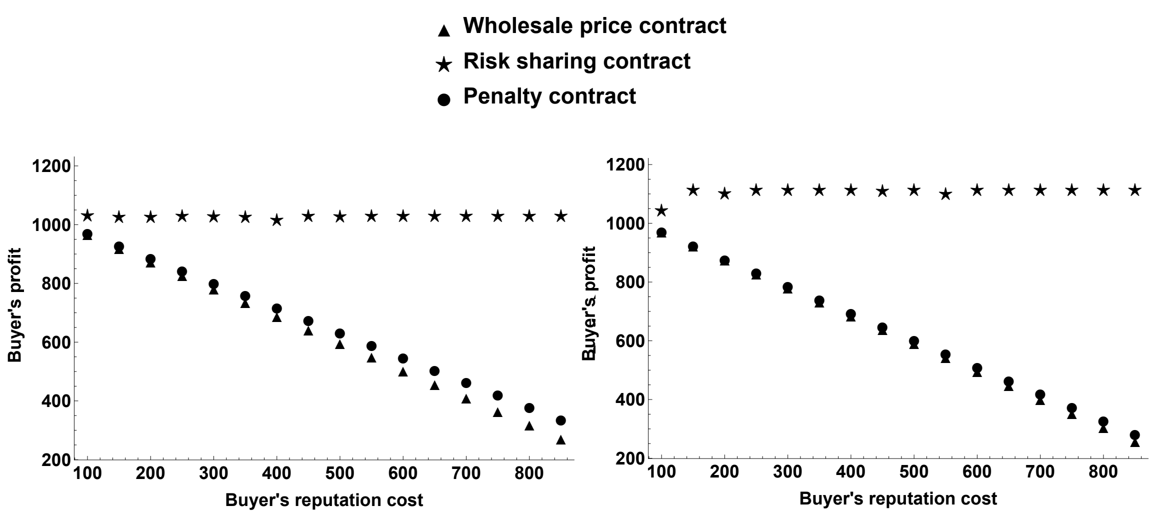
$$\Delta = \underbrace{(1-F_M(e_b^p))R_S^*+(1-F_S(e_b^r,e_g^r))\delta^*X_S+(e_b+e_g)^p-(e_b+e_g)^r}_{\geq 0 \text{ using Proposition 6(i)}}+\underbrace{(F_M(e_b^p)-F_M(e_b^r))}_{\leq 0 \text{ if } MRS\leq\Theta_1}R_M$$

Clearly, as long as reputation costs are not too high, risk-sharing is better for the buyer than a penalty contract even if the former increases supplier violations. This assertion is reflected in Figure 3 where our numerical analysis shows that risk-sharing outperforms a penalty contract for low values of reputation cost. This is despite the fact that risk-sharing leads to the highest bad effort and the lowest good effort among the three contracts. In other words, although a penalty is better for reducing supplier violations, the buyer may nonetheless choose risk-sharing simply to negotiate a lower contract price. This indicates that risk-sharing can be especially valuable for the buyer when the supplier is a small wealth-constrained firm with limited bargaining power. In the other two cases, when MRS $> \Theta_1$, risk-sharing also reduces supplier violations. Our numerical experiments indicate that, in these scenarios, risk-sharing actually performs better than penalty in reducing violations for higher values of reputation cost. This is not surprising for the following reason. As reputation cost increases, the buyer would want to charge a higher penalty; which in turn necessitates a greater transfer payment due to limited liability. This same issue does not arise in risk-sharing because it weakens the supplier's wealth constraint. Therefore, as reputation cost increases, the buyer can leverage risk-sharing to reduce both violations *and* contract payment without any significant loss. In our numerical experiments, risk-sharing increases the buyer's profit by up to 300% relative to a penalty when MRS $> \Theta_1$. The two cases are illustrated in Figure 4. In these cases, the buyer's profit under risk sharing remains unchanged despite an increase in reputation cost. The reason is that risk sharing reduces the supplier's bad effort to zero. As a result, the buyer faces no negative externality with an increase in reputation cost.



$X_M = 50$, $X_S = 100$, $K = 20$, $V = 1200$, $F_S(e_b, e_g) = 1/((1+e_b)^{0.7}(0.5+exp(e_g))^{0.3})$, $F_M(e_b) = e_b^{0.5}/(1+e_b)^{0.5}$

Figure 3: Comparison of the three contracts when $MRS \leq \Theta_1$.



(a) MRS $\in (\Theta_1, \Theta_2)$; $F_S(e_b, e_g) = 1/((1+e_b)^{0.5}(1+e_g)^{0.5})$

(b) MRS $\geq \Theta_2$; $F_S(e_b, e_g) = 1/((0.5+exp(e_b))^{0.3}(1+e_g)^{0.7})$

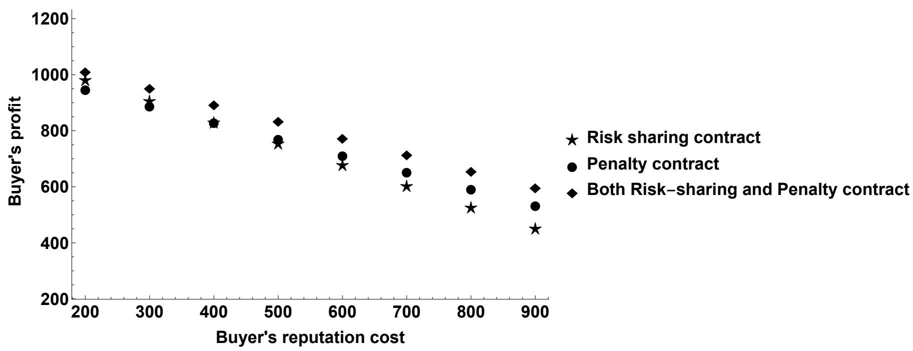
$X_M = 50$, $X_S = 100$, $K = 20$, $V = 1200$, $F_M(e_b) = e_b^{0.5}/(1+e_b)^{0.5}$

Figure 4: Buyer's profit under the three contracts when $MRS > \Theta_1$.

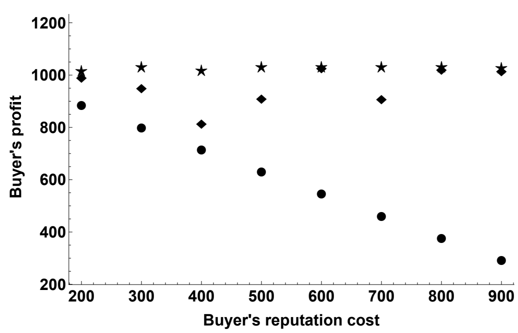
6.1 Contracting with both risk-sharing and penalty

Given that penalties attain outcomes closer to the centralized levels and risk-sharing allows squeezing supplier margins, can a contract that combines these two elements be more effective in managing reputation risk? Consider, for example, a "two-way risk sharing" contract where (i) the buyer imposes a penalty to transfer a part of its reputation damage to the supplier, and (ii) provides a risk-coverage that transfers part of the supplier's operational damage to the buyer.

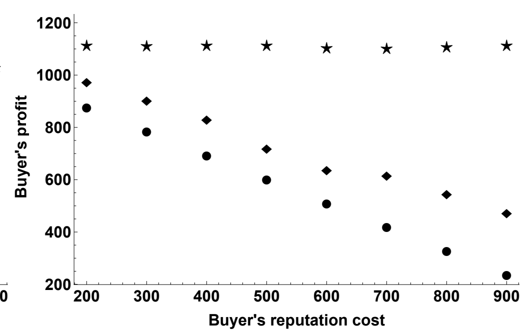
We argue that this two-way risk-sharing contract may not necessarily be better than risk-sharing alone. The reason is as follows. Imposing a penalty on the supplier will have a negative first order effect on the buyer's profit due to an increased transfer payment. Any benefit of a penalty in terms of improved supplier responsibility will have a second order impact through change in optimal efforts. So unless risk-sharing worsens reputation risk (i.e., $MRS \leq \Theta_1$) and R_M is very large, adding a penalty component to the contract may not be beneficial for the buyer. This is illustrated in our numerical experiments in Figure 5. A "two-way" risk-sharing contract is better only when $MRS \leq \Theta_1$, but when $MRS > \Theta_1$ the buyer achieves its highest profit through risk-sharing alone.



(a) $MRS \leq \Theta_1$;
$F_S(e_b, e_g) = 1/((1+e_b)^{0.7}(0.5+exp(e_g))^{0.3})$



(b) $MRS \in (\Theta_1, \Theta_2)$;
$F_S(e_b, e_g) = 1/((1+e_b)^{0.7}(0.5+exp(e_g))^{0.7})$



(c) $MRS \geq \Theta_2$;
$F_S(e_b, e_g) = 1/((0.5+exp(e_b))^{0.3}(1+e_g)^{0.7})$

$X_M = 50$, $X_S = 100$, $K = 20$, $V = 1200$, $F_M(e_b) = e_b^{0.5}/(1+e_b)^{0.5}$

Figure 5: Risk-sharing and penalty versus the composite contract.

7 Extensions

7.1 Dual-sourcing under reputation risk

In the absence of any reputational issues, a buyer could manage its operational risk by sourcing from multiple suppliers. But this strategy may be sub-optimal when reputation is a serious concern as it leads to more points of risk exposure. In this subsection, we formally study the role of dual-sourcing under reputation risk and explore how it interacts with risk-sharing.

Suppose that the multinational sources from two independent and identical suppliers, A and B who provide quantities q_A and q_B, respectively. The buyer can either (i) split the single source order quantity (of one unit) between the two suppliers (to hedge against operational risk at any one supplier), or (ii) procure an additional quantity (above one unit) from the suppliers to act as a "safety stock" against any operational loss. We, therefore, consider the total order quantity, $q_A + q_B \in [1, 2]$. When $q_A + q_B = 1$, the buyer procures half a unit from each identical supplier. At the other extreme, the buyer sources twice the order quantity it needs – one unit from *each* supplier.

Each supplier exerts bad and good effort to mitigate its operational risk, $F_{S,i}(e_b, e_g)$ where $i \in \{A, B\}$. The buyer faces a reputation risk $F_{M,i}(e_b)$ if either supplier, $i \in \{A, B\}$, exerts bad effort. Dual-sourcing also allows the buyer to contain the magnitude of operational loss as production capacities can be transferred between the suppliers. For instance, if avian flu outbreak occurs at one farm, a food company may be able to source additional eggs from its other farm. The buyer will bear the full weight of its operational loss, X_M, only when risk is realized for both suppliers.

If risk materializes for only one of the supplier, the buyer incurs an operational loss $\lambda(1-q_{-i})X_M$ for $i \in \{A, B\}$ where $\lambda \in [0, 1)$ represents the extent to which quantities can be redistributed between the suppliers after a disruption occurs. For instance, suppose the buyer procures 0.6 units from each supplier and risk materializes for Supplier A. In this case, the buyer incurs *less than 40%* of the total operational loss because (i) Supplier B provides 0.6 units, and (ii) there is an exogenous flexibility, λ, that allows some production to be shifted from Supplier A to Supplier B ex-post.

Because the suppliers are identical, they have the same operational risk functions, $F_{S,A} = F_{S,B}$, and the buyer sources quantities $q_A = q_B$. Define $c = \lambda(1 - q_A) = \lambda(1 - q_B)$. It is easy to verify that $0 \leq c \leq 0.5\lambda$. Then, the buyer's operational loss distribution can be written as follows.

$$\text{Multinational's operational loss} = \begin{cases} X_M, & \text{w.p. } F_{S,A}F_{S,B} = F_{S,A}^2 \\ \lambda(1-q_A)X_M = cX_M, & \text{w.p. } (1-F_{S,A})F_{S,B} = (1-F_{S,A})F_{S,A} \\ \lambda(1-q_B)X_M = cX_M, & \text{w.p. } (1-F_{S,B})F_{S,A} = (1-F_{S,A})F_{S,A} \\ 0, & \text{w.p. } (1-F_{S,A})(1-F_{S,B}) = (1-F_{S,A})^2 \end{cases}$$

The buyer's expected operational loss is, therefore, $X_M(1-2c)F_{S,A}^2 + 2cX_MF_{S,A}$. Note that this is less than the loss under single sourcing because $X_M(1-2c)F_{S,A}^2 + 2cX_MF_{S,A} < X_M(1-2c)F_{S,A} + 2cX_MF_{S,A} = X_MF_{S,A}$.[15]

In contrast to operational loss, the multinational firm would face the full brunt of reputational loss, R_M, even if one of its supplier commits a responsibility violation. For example, suppose that only one of the two farms supplying a food company is revealed to engage in animal abuse. The buyer could then face brand damage and pressure from stakeholders regardless of the quantity of products being sourced from this supplier. Reallocating some production to the other farm is unlikely to ameliorate any reputation harm in this case. In this sense, reputation risk cannot be "diversified away." The buyer's expected reputation loss is, therefore, $-R_MF_{M,A}^2 + 2R_MF_{M,A} > -R_MF_{M,A} + 2R_MF_{M,A} = R_MF_{M,A}$ which is its expected reputation loss under single sourcing.

From the above analysis, we have that dual sourcing decreases the buyer's operational cost, and increases its reputation cost in expectation. What remains to be seen is its impact on the sourcing cost i.e., the total transfer payment to the suppliers. To that end, we can write the multinational's problem under dual-sourcing as follows.

$$\begin{aligned} \max_{T,q_A,q_B\geq 0} E\Pi_{M,D} &= V - (q_A+q_B)T - 2cX_MF_{S,A} - X_MF_{S,A}^2(1-2c) - 2R_MF_{M,A} + R_MF_{M,A}^2 \\ \text{subject to} \quad q_iT &- X_S - q_iK - e_{b,i} - e_{g,i} \geq 0 \text{ for } i \in \{A,B\} \\ q_iT &- F_{S,i}X_S - q_iK - e_{b,i} - e_{g,i} \geq 0 \text{ for } i \in \{A,B\} \\ (e_{b,i}, e_{g,i}) &\in \arg\max_{e_b,e_g\geq 0} q_iT - F_{S,i}X_S - q_iK - e_{b,i} - e_{g,i} \text{ for } i \in \{A,B\} \\ \sum_{i\in\{A,B\}} q_i &\in [1,2]; E\Pi_{M,D} \geq 0 \end{aligned}$$

As limited liability constraints bind at optimality, we have $(q_A+q_B)T^* = 2X_S + (q_A+q_B)K +$

[15]Observe that $1-2c > 0$. This is because $q_A + q_B \in [1,2]$ and identical suppliers $\implies q_A = q_B \in [0.5,1] \implies c \in [0, 0.5\lambda] \implies 0 \leq 2c \leq \lambda < 1$.

$e^*_{b,A} + e^*_{g,A} + e^*_{b,B} + e^*_{g,B}$. Clearly, this transfer payment is higher than that under single sourcing.[16] Therefore, dual sourcing decreases operational cost but increases both reputation and sourcing costs for the buyer. Consequently, the buyer should prefer single sourcing when reputation costs are a significant concern. Formally, this can be seen by comparing the buyer's maximal profit under the two strategies as follows.

$$E\Pi_{M,D} = V - 2X_S - (q_A + q_B)K - 2(e_{b,A} + e_{g,A}) - 2cX_M F_{S,A} - X_M F_{S,A}^2(1-2c) - 2R_M F_{M,A} + R_M F_{M,A}^2$$

$$E\Pi_{M,S} = V - X_S - K - (e_{b,A} + e_{g,A}) - X_M F_{S,A} - R_M F_{M,A}$$

$$\begin{aligned} E\Pi_{M,D} - E\Pi_{M,S} &= -X_S - K(q_A + q_B - 1) - (e_{b,A} + e_{g,A}) \\ &\quad +(1-2c)X_M F_{S,A}(1 - F_{S,A}) - R_M F_{M,A}(1 - F_{M,A}) \\ &\leq X_M - R_M F_{M,A}(1 - F_{M,A}) \end{aligned}$$

It is clear from the above expression that single sourcing is a superior strategy for the buyer when its reputation cost is large ($R_M \to \infty$) or operational cost is small ($X_M \to 0$) as $E\Pi_{M,D} - E\Pi_{M,S} < 0$.

7.1.1 Risk-sharing versus Dual-sourcing

In the above analysis, we show how dual-sourcing can exacerbate the buyer's reputation cost in comparison to a wholesale price contract. In this section, we discuss how dual-sourcing compares with risk-sharing in managing the buyer's risks and costs. In other words, which contract should the buyer choose when considering a switch from a wholesale price single-sourcing strategy?

We find that risk-sharing generally leads to an opposite effect than dual-sourcing. As discussed in the previous section, dual sourcing always decreases the buyer's operational cost but increases reputation and sourcing costs. On the other hand, when $MRS > \Theta_1$, risk-sharing *increases* the buyer's operational cost while *decreasing* reputation and sourcing costs. When $MRS \leq \Theta_1$, both risk-sharing and dual-sourcing increase the buyer's reputation costs. But the operational cost will be lower and transfer payment will be higher under dual-sourcing (see Table 1 for a summary).

Table 1: Risk-sharing and Dual-sourcing relative to Single sourcing with wholesale price

	Operational cost	Reputation cost	Transfer payment
Dual-sourcing	Reduces	Increases	Increases
Risk-sharing (MRS $> \Theta_1$)	Increases	Decreases	Decreases
Risk-sharing (MRS $\leq \Theta_1$)	Increases	Increases	Decreases

[16] Recall that the transfer payment under single sourcing was $T^* = X_S + K + e_{b,A} + e_{g,A}$. In our stylized model, the supplier's efforts do not depend on the sourcing quantity or the transfer payment. They are determined only by the supplier's expected operational risk and cost of efforts, and these parameters are unchanged by dual sourcing.

This indicates that the two mechanisms do not play a complementary role in the buyer's risk-management toolkit. Although dual sourcing reduces the expected operational cost, it does so at the expense of increasing the reputation and sourcing costs for the buyer. And risk-sharing has the opposite effect (under some conditions.) This suggests that the buyer should opt for dual-sourcing if it operates in an industry where X_M is more significant than R_M. But for a consumer facing buyer whose reputation cost can be quite large, risk-sharing may be a more suitable strategy.

In practice, for example, automotive parts and medical equipment manufacturers typically source from multiple suppliers. This is because their processes are often subject to regulatory approval or safety tests which can take several months. Consequently, they cannot wait until a disruption occurs to find alternative suppliers or put in place a new manufacturing system as it can substantially increase their time to recovery (Sheffi, 2015). Large consumer-facing companies, on the other hand, may find it better to source from a select group of suppliers to reduce reputation risk. The restaurant chain, Chipotle, for instance, purposely procures some key food ingredients from a small set of suppliers to ensure sustainable farming practices (Chipotle, 2017). Similarly, pharmaceutical company Pfizer consolidated its supply base to avoid social responsibility risks (Sheffi, 2015).

To summarize, dual sourcing is ideal in settings where operational costs can be significant for the buyer, and reputation costs are not that high. In contrast, risk-sharing is more suitable when the focus is on curtailing reputation risk and lowering input prices.

7.2 Production cost and supplier violations

In some instances, a supplier can reduce both operational risk and production cost by taking the same non-compliant action. Consider, for instance, the case of antibiotics usage in farming. While the primary motive may be to stave off diseases, using antibiotics also accelerates animal growth rate so the livestock reach desired slaughter weight in a shorter time-span. This, in turn, allows farmers to improve feed efficiency and cut the operational expenses of animal husbandry in addition to mitigating yield risk. We extend our base model to include such scenarios where supplier's bad effort reduces both operational risk and cost. We find that the results in Proposition 2 are largely robust to this extension, except that the threshold at which risk-sharing increases good effort is increased. For details, see Appendix B.3.

7.3 Role of supplier's net equity

Our model thus far assumes that the supplier must earn a non-negative profit in the worst-case scenario. In Appendix B.4, we explore the role of a risk-sharing contract when this condition is relaxed. Specifically, suppose that the supplier could go insolvent under the contract but its maximum loss must be capped at a general net equity level E. If $E \geq 0$, we can think of it as the cash reserves of the supplier. Conversely, $E < 0$ would imply that the supplier has debt payments that are due. The supplier's limited liability constraint is then given by $T-(1-\delta)X_S-K-e_b-e_g \geq -E$.

We find that this generalization of the limited liability constraint alters the condition under which the multinational would offer risk-sharing. Since the value of E determines whether or not the limited liability constraint binds, the result from Proposition 3 continues to hold when $E \leq 0$. In contrast, when the supplier can withstand large losses ($E > 0$), a risk-sharing contract may no longer beneficial for the buyer. For details, see Appendix B.4.

8 Conclusion

In this paper, we show an important role for risk-sharing in managing reputational issues in supply chains. To the best of our knowledge, this has not been considered by practitioners and researchers alike. This is especially pertinent given that multinationals are increasingly assumed to be complicit in any social or environmental violation by their suppliers. We also contribute to the academic literature by highlighting the non-trivial implications of risk-sharing in multi-task agency models.

Specifically, we consider a setting where a large multinational firm engages with a small wealth-constrained supplier. The supplier faces an operational risk and may adopt questionable business practices to mitigate it. Suppliers frequently choose to exert "bad effort" (e.g., use of harmful inputs) over "good effort" (e.g., process improvements) to achieve their risk and cost reduction goals. The buyer can not directly observe or control these efforts. Both bad and good effort reduce operational risk in the supply chain, but bad effort *increases* reputation risk for the buyer.

To manage the buyer's reputation risk, we propose a risk-sharing contract where the buyer offers to compensate a predetermined portion of the supplier's operational loss. We find that sharing the supplier's risk can either decrease or increase bad effort. A supplier's response to risk-sharing may depend on institutional factors in the country of origin which may influence the relative ease of exerting good and bad effort. In particular, risk-sharing may be more effective at curbing violations by a supplier operating under weak regulatory oversight. And it may backfire if the supplier is subject to strict government and public scrutiny.

By leveraging the supplier's response to risk-sharing, we find that the buyer can (subject to some conditions) benefit whether bad effort increases or decreases. When bad effort decreases, the buyer benefits through a lower reputation risk. And when bad effort increases, risk-sharing allows the buyer to restrict the worst-case liability payment to the supplier. This indicates that even when the welfare implication of risk-sharing is negative, it can still be valuable for the buyer.

We also study the interplay between risk-sharing and conventional procurement strategies like dual-sourcing and non-compliance penalties when the supplier has limited liability. We show that conventional procurement strategies may fall short when considering reputational risk and sourcing costs along with operational risk. For example, we show that dual-sourcing reduces operational risk but increases operational risk and sourcing costs. Non-compliance penalties can reduce reputation risk but increase the cost of sourcing from a wealth-constrained supplier. This indicates that risk-sharing can be superior, as a procurement strategy, to conventional approaches when reputation and sourcing costs are a significant concern and operational costs are not that high.

The stylized model considered in this paper can be expanded in several directions. It will be interesting to examine, for example, the shift in consumer preferences and demand due to supplier misconduct. Additionally, we assume that a multinational's reputation loss can be quantified. In reality, estimating the value of reputation damage a priori can be quite difficult for the firms. Studying the interplay between bad and good effort in addressing supply chain social responsibility when reputation costs are unknown may lead to interesting insights.

Acknowledgments: The authors thank the department editor, the associate editor, and three anonymous referees for their valuable comments, which substantially helped to improve this paper. The authors also thank James Vercammen for providing early feedback on the paper.

References

Annan, F. and Schlenker, W. (2015). Federal crop insurance and the disincentive to adapt to extreme heat. *American Economic Review: Papers and Proceedings*, 105.

Babich, V. and Tang, C. S. (2012). Managing Opportunistic Supplier Product Adulteration: Deferred Payments, Inspection, and Combined Mechanisms. *Manufacturing & Service Operations Management*, 14(2):301–314.

Bakshi, N., Kim, S.-H., and Savva, N. (2015). Signaling new product reliability with after-sales service contracts. *Management Science*, 61(8):1812–1829.

Bjerga, A. (2016). Giving Veterinarians Police Power. *Bloomberg*.

Bloomberg (2009). Pork drops 30% in Futures as flu cuts Chinese imports.

Bolton, P. and Dewatripont, M. (2004). *Contract Theory*. The MIT Press.

Caro, F., Chintapalli, P., Rajaram, K., and Tang, C. S. (2018). Improving supplier compliance through joint and shared audits with collective penalty. *Manufacturing & Service Operations Management*, 20(2):363–380.

Cermaq Global (2018). Transparent about our performance.

Chen, J., Qi, A., and Dawande, M. (2019a). Supplier Centrality and Auditing Priority in Socially-Responsible Supply Chains. *Manufacturing & Service Operations Management*. Forthcoming.

Chen, L. and Lee, H. (2017). Sourcing under Supplier Responsibility Risk : The Effects of Certification, Audit and Contingency Payment. *Management Science*, 63(9):2795–2812.

Chen, L., Yao, S., and Zhu, K. (2019b). Responsible Sourcing under Supplier-Auditor Collusion. *Manufacturing & Service Operations Management*. Forthcoming.

Chen, S., Lee, H., and Moinzadeh, K. (2016). Supply chain coordination with multiple shipments: The optimal inventory subsidizing contracts. *Operations Research*, 64(6):1320–1337.

Chen, S., Zhang, Q., and Zhou, Y.-P. (2019c). Impact of supply chain transparency on sustainability under ngo scrutiny. *Production and Operations Management*, 28(12):3002–3022.

Chipotle (2017). Chipotle Mexican Grill: Annual Report 2017.

Cho, S.-H., Fang, X., Tayur, S., and Xu, Y. (2019). Combating child labor: Incentives and information disclosure in global supply chains. *Manufacturing & Service Operations Management*, 21(3):692–711.

Deloitte (2014). Reputation@Risk: 2014 global survey on reputation risk. Technical report.

Dong, L. and Tomlin, B. (2012). Managing disruption risk: The interplay between operations and insurance. *Management Science*, 58(10):1898–1915.

Einen, O. (2013). Cermaq's approach to preventive fish health - a team play. *Cermaq Global*.

Esposito, A. (2015). Addicted to antibiotics, Chile's salmon flops at Costco, grocer.

FAIRR (2016). Factory Farming: Assessing Investment Risks. Technical report. Research by Verisk Maplecroft, p. 28.

Fang, X. and Cho, S. (2015). Cooperative approaches to managing social responsibility in supply chains: Joint auditing and information sharing. Working paper.

Federgruen, A., Upmanu, L., and Simsek, A. (2019). Supply chain analysis of contract farming.

Financial Times (2016). A tale of two fisheries: Fortunes of Norway and Chile diverge.

Fitzpatrick, H. (2015). A national egg shortage is threatening fast food breakfast. *Business Insider*.

Gan, X., Sethi, S., and Yan, H. (2005). Channel coordination with a risk-neutral supplier and a downside-risk-averse retailer. *Production and Operations Management*, 14(1):80–89.

Global Aquaculture Performance Index (2011). GAPI indicators: Antibiotics.

Guo, R., Lee, H. L., and Swinney, R. (2016). Responsible sourcing in supply chains. *Management Science*, 62(9):2722–2744.

Hennessey, D. (2007). Behavioral incentives, equilibrium endemic disease, and health management policy for farmed animals. *American Journal of Agricultural Economics*, 89.

Huang, L., Song, J.-S., and Swinney, R. (2017). Managing Social Responsibility in Multi-tier Supply Chains. Working paper.

Kalkanci, B. and Plambeck, E. (2019). Managing Supplier Social & Environmental Impacts with Voluntary vs. Mandatory Disclosure to Investors. *Management Science*. Forthcoming.

Kim, S.-H., Cohen, M. A., and Netessine, S. (2007). Performance contracting in after-sales service supply chains. *Management Science*, 53(12):1843–1858.

Kim, S.-H., Cohen, M. A., Netessine, S., and Veeraraghavan, S. (2010). Contracting for infrequent restoration and recovery of mission-critical systems. *Management Science*, 56(9):1551–1567.

Kraft, T., Valdés, L., and Zheng, Y. (2017). Transparency in Social Responsibility: Investigating Consumers' Behaviors and Motives. *Manufacturing & Service Operations Management*. Forthcoming.

Lewis, T. R., Liu, F., and Song, J.-S. (2019). A Dynamic Mechanism for Achieving Sustainable Quality Supply. Working paper.

Li, C.-L. and Kouvelis, P. (1999). Flexible and risk-sharing supply contracts under price uncertainty. *Management Science*, 45(10):1378–1398.

Mas-Colell, A., Whinston, M., and Green, J. (1995). *Microeconomic Theory*. New York: Oxford University Press.

McEwen, S., Angulo, F., Collignon, P., and Conly, J. (2018). Unintended consequences associated with national-level restrictions on antimicrobial use in food-producing animals. *The Lancet Planetary Health*, 2(7):e279 – e282.

National Chicken Council (2017). U.S. Broiler Performance.

NRDC et al. (2016). Chain Reaction II: How Top Restaurants Rate on Reducing Use of Antibiotics in Their Meat Supply. Technical report, Natural Resources Defense Council.

Orsdemir, A., Hu, B., and Deshpande, V. (2019). Ensuring corporate social and environmental responsibility through vertical integration and horizontal sourcing. *Manufacturing & Service Operations Management*, 21(2):417–434.

Plambeck, E. and Zenios, S. (2003). Incentive efficient control of a make-to-stock production system. *Operations Research*, 51(3):371–386.

Plambeck, E. L. and Taylor, T. A. (2016). Supplier evasion of a buyer's audit: Implications for motivating supplier social and environmental responsibility. *Manufacturing & Service Operations Management*, 18(2):184–197.

Rui, H. and Lai, G. (2015). Sourcing with Deferred Payment and Inspection under Supplier Product Adulteration Risk. *Production and Operations Management*, 24(6):934–946.

Sappington, D. (1983). Limited liability contracts between principal and agent. *Journal of Economic Theory*, 29(1):1–21.

Serpa, J. and Krishnan, H. (2017). The strategic role of business insurance. *Management Science*, 63(2):384–404.

Sheffi, Y. (2015). *The Power of Resilience: How the Best Companies Manage the Unexpected*. MIT Press.

Short, J., Toffel, M., and Hugil, A. (2016). Monitoring global supply chains. *Strategic Management Journal*, 37(9):1878–1897.

Strom, S. (2015). Food Companies Fear Bird Flu May Cause Egg Shortages. *New York Times*.

Terazono, E. (2017). Norway turns to radical salmon farming methods. *Financial Times*.

The Guardian (2015). Egg prices in the US nearly double after outbreak of avian flu.

Tommasi, M. and Weinschelbaum, F. (2007). Principal-agent contracts under the threat of insurance. *Journal of Institutional Theoretical Economics*, 163(3):379–393.

Topkis, D. (1978). Minimizing a Submodular Function on a Lattice. *Operations Research*, 26.

Wang, Y., Gilland, W., and Tomlin, B. (2010). Mitigating supply risk: Dual sourcing or process improvement? *Manufacturing & Service Operations Management*, 12(3):489–510.

Wegener, H. C., Aarestrup, F. M., Jensen, L. B., Hammerum, A. M., and Bager, F. (1999). Use of Antimicrobial Growth Promoters in Food Animals and Enterococcus faecium Resistance to Therapeutic Antimicrobial Drugs in Europe. *Emerging Infectious Diseases*, 5:329–335.

Winter, R. (2000). Optimal insurance under moral hazard. In Dionne G., editor, *Handbook of Insurance: Huebner International Series on Risk, Insurance, and Economic Security*, volume 22, chapter 6, pages 155–183. Springer.

Zhang, H., Aydin, G., and Heese, H. (2019). Curbing the Usage of Conflict Minerals: A Supply Network Perspective. Working paper.

Online Appendix

Appendix A Proofs

Proof of Proposition 1. Consider the problem $\max_{e_b\geq 0, e_g\geq 0}\Psi(e_b,e_g,\Omega)=\max_{e_b\geq 0, e_g\geq 0}\Omega E\Pi_C+(1-\Omega)E\Pi_S$ where Ω is the indicator for $E\Pi_C$ i.e.,

$$\Psi(e_b,e_g,\Omega) = \begin{cases} E\Pi_C, & \text{if } \Omega=1 \\ E\Pi_S, & \text{if } \Omega=0 \end{cases}$$

The choice set for this problem, $[0,\infty)\times[0,\infty)$, is again a lattice. The new objective function is supermodular in $(e_g,-e_b)$ as $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial e_g\partial e_b}=-(\Omega X_M+X_S)\frac{\partial^2 F_S(e_b,e_g)}{\partial e_g\partial e_b}<0$. We will have increasing differences in $(e_g,-e_b,\Omega)$ if $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial e_g\partial e_b}\leq 0$, $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial\Omega\partial e_g}\geq 0$, and $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial\Omega\partial e_b}\leq 0$. This is true because $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial e_g\partial e_b}<0$ (as shown earlier), $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial\Omega\partial e_g}=-X_M\frac{\partial F_S(e_b,e_g)}{\partial e_g}>0$, and $\frac{\partial^2\Psi(e_b,e_g,\Omega)}{\partial\Omega\partial e_b}=-X_M\frac{\partial F_S(e_b,e_g)}{\partial e_b}-R_M\frac{dF_M(e_b)}{de_b}<0$ if $\frac{dF_M(e_b)}{de_b}>-\frac{X_M}{R_M}\frac{\partial F_S(e_b,e_g)}{\partial e_b}$. Therefore, when this condition is met, e_b^* is (weakly) decreasing in Ω and e_g^* is (weakly) increasing in Ω (by Topkis's monotonicity theorem (Topkis, 1978)). As Ω is the indicator for centralized firm's problem, we get $e_b^w>e_b^c$ and $e_g^w<e_g^c$. □

Proof of Lemma 1. The condition $\lim_{e_b\to 0}\frac{\partial F_S(e_b,e_g)}{\partial e_b}<\lim_{e_b\to 0}\frac{\partial F_S(e_b,e_g)}{\partial e_g}$ implies that $\lim_{e_b\to 0}MRS>1$ for all $e_g\geq 0$. Now, suppose that at optimality $e_b^r=0$ and $e_g^r>0$. Then first order necessary conditions imply that $\frac{\partial E\Pi_S}{\partial e_b}(e_b^r,e_g^r)\leq 0$ and $\frac{\partial E\Pi_S}{\partial e_g}(e_b^r,e_g^r)=0$. This is equivalent to $-\frac{\partial F_S}{\partial e_b}(e_b^r,e_g^r)\leq\frac{1}{(1-\delta)X_S}$ and $-\frac{\partial F_S}{\partial e_g}(e_b^r,e_g^r)=\frac{1}{(1-\delta)X_S}$. Dividing the above two inequalities, we get $e_b^r=0$ and $e_g^r>0\implies \text{MRS}_{e_b^r,e_g^r}\leq 1$ which contradicts the condition in the lemma. Similarly, we can show that if $e_b^r>0$ and $e_g^r=0$, then it must be that $\text{MRS}_{e_b^r e_g^r}\geq 1$ which contradicts that $\lim_{e_g\to 0}\frac{\partial F_S(e_b,e_g)}{\partial e_b}>\lim_{e_g\to 0}\frac{\partial F_S(e_b,e_g)}{\partial e_g}$ or equivalently that $\lim_{e_g\to 0}MRS<1$ for all $e_b\geq 0$. □

Proof of Proposition 2. Observe that the supplier's problem under wholesale price contract is the same as the supplier's problem under risk-sharing contract with zero coverage i.e., $\delta=0$. The coverage level is an exogenous parameter for the supplier. We, therefore, examine how supplier's optimal efforts under risk-sharing contract change as we change the coverage level $\delta\in[0,1)$. To do so, we use the implicit function theorem. As the supplier's objective is concave (following from the joint convexity of $F_S(e_b,e_g)$), the first order necessary conditions are also sufficient. As our focus is on interior optimal solutions ($e_b^r>0$ and $e_g^r>0$), the first order conditions for the risk-sharing contract are given as follows.

$$-(1-\delta)X_S\frac{\partial F_S}{\partial e_b}(e_b^r(\delta,X_S),e_g^r(\delta,X_S))-1=0, \text{ and, } -(1-\delta)X_S\frac{\partial F_S}{\partial e_g}(e_b^r(\delta,X_S),e_g^r(\delta,X_S))-1=0$$

In the remainder of the proof, we omit the arguments (δ, X_S) from optimal efforts for succinctness. Differentiating above equations with respect to δ, we get the following.

$$\underbrace{\begin{bmatrix} -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b^2}(e_b^r, e_g^r) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^r, e_g^r) \\ -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^r, e_g^r) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_g^2}(e_b^r, e_g^r) \end{bmatrix}}_{\mathbf{H}} \begin{bmatrix} \frac{\partial e_b^r}{\partial \delta} \\ \frac{\partial e_g^r}{\partial \delta} \end{bmatrix} = \begin{bmatrix} -X_S\frac{\partial F_S}{\partial e_b}(e_b^r, e_g^r) \\ -X_S\frac{\partial F_S}{\partial e_g}(e_b^r, e_g^r) \end{bmatrix}$$

Solving the above system of equations using Cramer's rule, we get,

$$\frac{\partial e_b^r}{\partial \delta} = \frac{1}{det(H)} \underbrace{\begin{vmatrix} -X_S\frac{\partial F_S}{\partial e_b}(e_b^r, e_g^r) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^r, e_g^r) \\ -X_S\frac{\partial F_S}{\partial e_g}(e_b^r, e_g^r) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_g^2}(e_b^r, e_g^r) \end{vmatrix}}_{J_{e_b}} \text{ and} \tag{1}$$

$$\frac{\partial e_g^r}{\partial \delta} = \frac{1}{det(H)} \underbrace{\begin{vmatrix} -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b^2}(e_b^r, e_g^r) & -X_S\frac{\partial F_S}{\partial e_b}(e_b^r, e_g^r) \\ -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^r, e_g^r) & -X_S\frac{\partial F_S}{\partial e_g}(e_b^r, e_g^r) \end{vmatrix}}_{J_{e_g}} \tag{2}$$

We first prove how risk-sharing changes individual effort components (part (ii) of the proposition), and then provide the proof of its impact on the sum of efforts (part (i) of the proposition).

Proof of part (ii) of the proposition:

Now, we are interested in the sign of the two partials $\frac{\partial e_b^r}{\partial \delta}$ and $\frac{\partial e_g^r}{\partial \delta}$. In Equations 1 and 2, observe that $det(H) = (1-\delta)^2 X_S^2 \left(\frac{\partial^2 F_S}{\partial e_b^2}(e_b^r, e_g^r)\frac{\partial^2 F_S}{\partial e_g^2}(e_b^r, e_g^r) - \left(\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^r, e_g^r)\right)^2 \right) > 0$ because the term in bracket represents the Hessian determinant of $F_S(e_b, e_g)$ at optimal efforts (e_b^r, e_g^r). As $F_S(e_b, e_g)$ is a convex function (by assumption), the hessian determinant is non-negative at all effort levels. To facilitate subsequent analysis, we restrict our attention to those functions, $F_S(e_b, e_g)$, whose hessian matrix is positive definite at all effort levels. Therefore, the sign of $\frac{\partial e_b^r}{\partial \delta}$ and $\frac{\partial e_g^r}{\partial \delta}$ depends on the sign of determinants J_{e_b} and J_{e_g}, respectively. Specifically, we have $\frac{\partial e_b^r}{\partial \delta} < 0$ if MRS $> \Theta_1$ for all (e_b, e_g), and $\frac{\partial e_g^r}{\partial \delta} < 0$ if MRS $< \Theta_2$ for all (e_b, e_g); where MRS $= \frac{\partial F_S}{\partial e_b} / \frac{\partial F_S}{\partial e_g}, \Theta_1 = \frac{\partial^2 F_S}{\partial e_b \partial e_g} / \frac{\partial^2 F_S}{\partial e_g^2}$, and $\Theta_2 = \frac{\partial^2 F_S}{\partial e_b^2} / \frac{\partial^2 F_S}{\partial e_b \partial e_g}$. Note that $\Theta_1 < \Theta_2$ because $\Theta_2 - \Theta_1 = \frac{\partial^2 F_S(e_b, e_g)}{\partial e_b^2}\frac{\partial^2 F_S(e_b, e_g)}{\partial e_g^2} - \left(\frac{\partial^2 F_S(e_b, e_g)}{\partial e_b \partial e_g}\right)^2 > 0$ as $F_S(e_b, e_g)$ is a convex function. Therefore, risk-sharing (i.e., $\delta > 0$) suppresses both bad and good effort if MRS $\in (\Theta_1, \Theta_2)$. Similarly, risk-sharing suppresses good effort and increases bad effort if MRS $\leq \Theta_1$. And finally, risk-sharing suppresses bad effort and increases good effort if MRS $\geq \Theta_2$.

Proof of part (i) of the proposition:

We can add the partials in Equations 1 and 2 to get the following.

$$\begin{aligned}\frac{\partial(e_b^r+e_g^r)}{\partial\delta} &= \frac{(1-\delta)X_S^2}{det(H)}\left(\frac{\partial F_S}{\partial e_b}\frac{\partial^2 F_S}{\partial e_g^2}-\frac{\partial^2 F_S}{\partial e_b\partial e_g}\frac{\partial F_S}{\partial e_g}+\frac{\partial F_S}{\partial e_g}\frac{\partial^2 F_S}{\partial e_b^2}-\frac{\partial^2 F_S}{\partial e_b\partial e_g}\frac{\partial F_S}{\partial e_b}\right)\Bigg|_{(e_b^r,e_g^r)}\\ &= \frac{(1-\delta)X_S^2}{det(H)}\left[\frac{\partial^2 F_S}{\partial e_b\partial e_g}\frac{\partial F_S}{\partial e_g}\left(\frac{\text{MRS}}{\Theta_1}-1+\Theta_2-\text{MRS}\right)\right]\Bigg|_{(e_b^r,e_g^r)}\\ &= \frac{(1-\delta)X_S^2}{det(H)}\left[\frac{1}{\Theta_1}\frac{\partial^2 F_S}{\partial e_b\partial e_g}\frac{\partial F_S}{\partial e_g}\left(\text{MRS}-\Theta_1+\Theta_1\Theta_2-\Theta_1\text{MRS}\right)\right]\Bigg|_{(e_b^r,e_g^r)}\end{aligned}$$

Now the supplier's first order conditions imply that at optimality, $(\text{MRS})|_{(e_b^r,e_g^r)}=1$. So we can write the above equation as follows.

$$\frac{\partial(e_b^r+e_g^r)}{\partial\delta} = \frac{(1-\delta)X_S^2}{det(H)}\left[\frac{1}{\Theta_1}\frac{\partial^2 F_S}{\partial e_b\partial e_g}\frac{\partial F_S}{\partial e_g}\left(1-\Theta_1+\Theta_1\Theta_2-\Theta_1\right)\right]\Bigg|_{(e_b^r,e_g^r)}$$

Note that $\frac{(1-\delta)X_S^2}{det(H)}\left[\frac{1}{\Theta_1}\frac{\partial^2 F_S}{\partial e_b\partial e_g}\frac{\partial F_S}{\partial e_g}\right]\Big|_{(e_b^r,e_g^r)}<0$ as by assumptions and convexity of $F_S(e_b,e_g)$, we have $\delta\in[0,1)$, $X_S>0$, $det(H)>0$. We also have that $\frac{\partial F_S}{\partial e_g}<0$, $\frac{\partial^2 F_S}{\partial e_b\partial e_g}>0$, and $\Theta_1>0$ for all (e_b,e_g). So to prove the claim, we only need to show that the term in parenthesis is positive. Consider $(1-\Theta_1+\Theta_1\Theta_2-\Theta_1)=(1-\Theta_1)+\Theta_1(\Theta_2-1)>(1-\Theta_1)+\Theta_1(\Theta_1-1)=(1-\Theta_1)^2\geq 0$ because $\Theta_2>\Theta_1$ and $\Theta_1>0$ for all (e_b,e_g). As this holds for all effort levels, it is true for optimal efforts (e_b^r,e_g^r). Therefore, we have that total optimal efforts reduce with risk-sharing i.e., $\frac{\partial(e_b^r+e_g^r)}{\partial\delta}<0$. □

Proof of Proposition 3. We assume that the market price, V, is high enough for the buyer's individual rationality constraint to be satisfied. As discussed in the paper, the supplier's limited liability constraint binds at optimality and individual rationality is non-binding. Therefore, we have $T^*=(1-\delta)X_S+K+e_g^r+e_b^r$. Substituting this optimal transfer price in the multinational's objective function, we get

$$\begin{aligned}\max_{\delta\in[0,1)} E\Pi_M &= V-(1-\delta)X_S-K-e_g^r-e_b^r-F_S(e_b^r,e_g^r)(X_M+\delta X_S)-F_M(e_b^r)R_M\\ \text{subject to} &\quad (e_b^r,e_g^r)\in\arg\max_{e_b,e_g\geq 0} T-F_S(e_b,e_g)(1-\delta)X_S-K-e_b-e_g\end{aligned}$$

As the supplier's problem is concave and our focus is on interior solutions, we can replace the incentive compatibility constraint by first order conditions: $\frac{\partial F_S}{\partial e_b}(e_b^r,e_g^r)=-\frac{1}{(1-\delta)X_S}$ and $\frac{\partial F_S}{\partial e_g}(e_b^r,e_g^r)=$

$-\frac{1}{(1-\delta)X_S}$. The multinational firm chooses $\delta^* > 0$ if $(\partial E\Pi^M/\partial\delta)|_{\delta=0} > 0$. Now,

$$\begin{aligned}\frac{\partial E\Pi^M}{\partial\delta} &= X_S(1-F_S(e_b^r,e_g^r)) - (\delta X_S + X_M)\left(\frac{\partial F_S}{\partial e_b}\frac{\partial e_b}{\partial\delta} + \frac{\partial F_S}{\partial e_g}\frac{\partial e_g}{\partial\delta}\right)\Bigg|_{(e_b^r,e_g^r)} \\ &- F_M'(e_b^r)\frac{\partial e_b^r}{\partial\delta}R_M - \frac{\partial e_b^r}{\partial\delta} - \frac{\partial e_g^r}{\partial\delta}\end{aligned}$$

Substitute first order conditions from incentive compatibility,

$$= \underbrace{\frac{\partial(e_b^r+e_g^r)}{\partial\delta}\left(\frac{\delta X_S + X_M}{(1-\delta)X_S} - 1\right) + X_S(1-F_S(e_b^r,e_g^r))}_{=u(X_S,X_M,\delta)} - F_M'(e_b^r)\frac{\partial e_b^r}{\partial\delta}R_M$$

Therefore, we have that $(\partial E\Pi^M/\partial\delta)|_{\delta=0} > 0$ if $F_M'(e_b^r)R_M(\partial e_b^r/\partial\delta)|_{\delta=0} < u(X_S,X_M,0)$

Proof of $u(X_S,X_M,0)$ increasing in X_S and decreasing in X_M:

$$\begin{aligned}\partial u(X_S,X_M,0)/\partial X_S &= -\frac{\partial(e_b^r+e_g^r)}{\partial\delta}\left(X_M/X_S^2\right) + (1-F_S(e_b^r,e_g^r)) + X_S\left(-\frac{\partial F_S}{\partial e_b}\frac{\partial e_b^r}{\partial X_S} - \frac{\partial F_S}{\partial e_g}\frac{\partial e_g^r}{\partial X_S}\right) \\ &= -\frac{\partial(e_b^r+e_g^r)}{\partial\delta}\left(X_M/X_S^2\right) + (1-F_S(e_b^r,e_g^r)) + X_S/((1-\delta)X_S)\frac{\partial(e_b^r+e_g^r)}{\partial X_S}\end{aligned}$$

(using first order conditions from supplier's problem under risk-sharing)

From proof of Proposition 2, we can show that $\partial(e_b^r+e_g^r)/\partial\delta < 0$ does not depend on X_S. Using Topkis' monotonicity theorem (Topkis, 1978), we can show that total effort increases with X_S i.e., $\partial(e_b^r+e_g^r)/\partial X_S > 0$. Therefore, $\partial u(X_S,X_M,0)/\partial X_S > 0$. Similarly, we have $\partial u(X_S,X_M,0)/\partial X_M = \frac{\partial(e_b^r+e_g^r)}{\partial\delta}/X_S < 0$. □

Proof of Proposition 4. From the proof of Proposition 3, we have

$$\frac{\partial E\Pi^M}{\partial\delta} = \frac{\partial(e_b^r+e_g^r)}{\partial\delta}\left(\frac{\delta X_S + X_M}{(1-\delta)X_S} - 1\right) + X_S(1-F_S(e_b^r,e_g^r)) - F_M'(e_b^r)\frac{\partial e_b^r}{\partial\delta}R_M$$

Case (i): $MRS > \Theta_1$

Recall from Proposition 2(ii) that in this case risk sharing reduces bad effort i.e., $\partial e_b^r/\partial\delta < 0$. Now,

$$\frac{\partial E\Pi^M}{\partial\delta} = \underbrace{\frac{\partial(e_b^r+e_g^r)}{\partial\delta}}_{\leq 0 \text{ from Proposition 2(i)}}\underbrace{\left(\frac{\delta X_S + X_M}{(1-\delta)X_S} - 1\right)}_{\substack{\leq 0 \text{ if} \\ \delta<(X_S-X_M)/(2X_S)}} + \underbrace{X_S(1-F_S(e_b^r,e_g^r))}_{\geq 0} - \underbrace{F_M'(e_b^r)R_M\frac{\partial e_b^r}{\partial\delta}}_{\leq 0 \text{ if } MRS>\Theta_1}$$

That is, when $MRS > \Theta_1$, the buyer's profit is increasing for $\delta < (X_S - X_M)/(2X_S)$. Therefore, the buyer will cover *at least* $(X_S - X_M)/(2X_S)$ of the supplier's operational loss. Further, as coverage level must be non-negative, we get that $\delta^* \geq (X_S - X_M)^+/(2X_S)$

Case (ii): $MRS \leq \Theta_1$

Recall from Proposition 2(ii) that in this case risk sharing increases bad effort i.e., $\partial e_b^r/\partial\delta > 0$. We show that, in this case, the buyer's profit is decreasing for $\delta > (X_S - X_M)/(2X_S)$ if $R_M \gg X_S$.

$$\frac{\partial E\Pi^M}{\partial\delta} = \underbrace{\frac{\partial(e_b^r + e_g^r)}{\partial\delta}}_{\leq 0 \text{ from Proposition 2(i)}} \underbrace{\left(\frac{\delta X_S + X_M}{(1-\delta)X_S} - 1\right)}_{\substack{\geq 0 \text{ if} \\ \delta > (X_S - X_M)/(2X_S)}} + \underbrace{X_S(1 - F_S(e_b^r, e_g^r))}_{\geq 0} - \underbrace{F'_M(e_b^r)R_M\frac{\partial e_b^r}{\partial\delta}}_{\geq 0 \text{ if } MRS \leq \Theta_1}$$

Therefore, $\frac{\partial E\Pi^M}{\partial\delta} \leq 0$ if $X_S(1 - F_S(e_b^r, e_g^r)) - F'_M(e_b^r)R_M\frac{\partial e_b^r}{\partial\delta} \leq 0$. Now,

$$\begin{aligned} X_S(1 - F_S(e_b^r, e_g^r)) - F'_M(e_b^r)R_M\frac{\partial e_b^r}{\partial\delta} &\leq X_S - F'_M(e_b^r)R_M\frac{\partial e_b^r}{\partial\delta} \text{ (because } F_S(e_b^r, e_g^r) \leq 1) \\ &\leq 0 \text{ if } R_M \geq X_S/\alpha \text{ where } \alpha = F'_M(e_b^r)\frac{\partial e_b^r}{\partial\delta} \end{aligned}$$

Therefore, when $MRS \leq \Theta_1$ and $R_M \gg X_S$, the buyer will cover *at most* $(X_S - X_M)^+/(2X_S)$ of the supplier's operational loss. □

Proof of Proposition 5. The supplier's problem under a wholesale price contract is given by $\max_{e_b \geq 0, e_g \geq 0} E\Pi_{S,W} = T - F_S(e_b, e_g)X_S - K - e_b - e_g$ and under a penalty contract is $\max_{e_b \geq 0, e_g \geq 0} E\Pi_{S,P} = T - F_S(e_b, e_g)X_S - F_M(e_b)R_S - K - e_b - e_g$. First note that as R_S increases, e_b decreases and e_g increases. This is easily verified by the supplier's problem under penalty, where the objective function has increasing differences in $(e_g, -e_b, R_S)$. This is because $\frac{\partial^2 E\Pi_{S,P}}{\partial R_S \partial e_b} = -\frac{dF_M(e_b)}{de_b} < 0$, $\frac{\partial^2 E\Pi_{S,P}}{\partial R_S \partial e_g} = -\frac{\partial F_M(e_b)}{\partial e_g} = 0$, and $\frac{\partial^2 E\Pi_{S,P}}{\partial e_b \partial e_g} = -\frac{\partial F_S(e_b, e_g)}{\partial e_b \partial e_g} X_S < 0$. Now, observe that the supplier's problem under a wholesale price contract is a special case of that under a penalty contract with $R_S = 0$. Therefore, we have $e_b^p < e_b^w$ and $e_g^p > e_g^w$.

We now compare the efforts under a penalty contract with the first-best effort levels. Recall that the centralized firm solves $\max_{e_b \geq 0, e_g \geq 0} E\Pi_C = V - F_S(e_b, e_g)(X_S + X_M) - F_M(e_b)R_M - K - e_b - e_g$. Proceeding exactly as in the proof of Proposition 1, consider the problem $\max_{e_b \geq 0, e_g \geq 0} \Psi(e_b, e_g, \Omega) = \max_{e_b \geq 0, e_g \geq 0} \Omega E\Pi_C + (1 - \Omega)E\Pi_{S,P}$ where Ω is the indicator for $E\Pi_C$ i.e.,

$$\Psi(e_b, e_g, \Omega) = \begin{cases} E\Pi_C, & \text{if } \Omega = 1 \\ E\Pi_{S,P}, & \text{if } \Omega = 0 \end{cases}$$

This new objective function will have increasing differences in $(e_g, -e_b, \Omega)$ if $(R_M - R_S)\frac{dF_M(e_b)}{de_b} > -X_M\frac{\partial F_S(e_b, e_g)}{\partial e_b}$. As Ω is the indicator for centralized firm's problem, using Topkis (1978) we get $e_b^p > e_b^c$ and $e_g^p < e_g^c$. Combining this with the previous result, we get $e_b^c < e_b^p < e_b^w$ and $e_g^c > e_g^p > e_g^w$ if $(R_M - R_S)\frac{dF_M(e_b)}{de_b} > -X_M\frac{\partial F_S(e_b, e_g)}{\partial e_b}$. □

Proof of Proposition 6. *Proof of part (i)*: We know from Proposition 2(i) that $e_b^r + e_g^r < e_b^w + e_g^w$. We need to show that $e_b^w + e_g^w < e_b^p + e_g^p$. Now the supplier's problem under wholesale price is a special case of that under penalty with $R_S = 0$. We, therefore, examine how the total effort changes as R_S increases. Let $a = e_b + e_g$. Then, the supplier's problem under a penalty contract is $\max_{a,e_b \geq 0} T - F_S(e_b, a - e_b)X_S - F_M(e_b)R_S - a$. It is easy to verify that the supplier's objective function in this case has increasing differences in $(-e_b, a, R_S)$. Therefore, by Topkis's monotonicity theorem (Topkis, 1978), total effort, a, increases as R_S increases. That is, $e_b^w + e_g^w < e_b^p + e_g^p$.
Proof of part (ii): Following arguments analogous to above, it is easy to verify that $e_b^p < e_b^w$ and $e_g^p > e_g^w$. From Proposition 2(ii), we know that $e_b^w < e_b^r$ if $MRS \leq \Theta_1$ and $e_g^w > e_g^r$ if $MRS \leq \Theta_2$. Combining these results, we get the condition in the proposition. □

Proof of Corollary 1. From Proposition 6(ii), we know that $e_b^p < e_b^r$ if $MRS \leq \Theta_1$. As reputation risk increases in bad effort, this implies that penalty has a lower reputation risk than risk-sharing when $MRS \leq \Theta_1$.

We now show that operational risk decreases in total effort. Let $a = e_b + e_g$, then operational risk, $F_S(e_b, e_g) = F_S(e_b, a - e_b)$ and $\frac{\partial F_S(e_b, a-e_b)}{\partial a} = \frac{\partial F_S(e_b, a-e_b)}{\partial e_g} < 0$. As total effort is the highest under a penalty (from Proposition 6(i)), this implies that operational risk is lower under a penalty contract than risk-sharing. □

Appendix B Additional Results

B.1 Benchmark case: Centralized supply chain

Suppose that the multinational firm and the supplier are organized as one centralized firm. In this situation, a contract between the two parties is not required. The centralized firm chooses efforts to maximize the expected profits for the entire supply chain, and solves the following problem.

$$\begin{aligned} \max_{e_b \geq 0, e_g \geq 0} E\Pi_C &= V - F_S(e_b, e_g)(X_S + X_M) - F_M(e_b)R_M - K - e_b - e_g \\ \text{subject to } E\Pi_C &\geq 0 \end{aligned}$$

We assume that the market revenue, V, is sufficiently high for the centralized firm to participate. That is, the constraint $E\Pi_C \geq 0$ is satisfied. Let e_b^c and e_g^c represent the optimal efforts chosen by the centralized firm. Then we have the following result.

Lemma B1. *As R_M increases, e_b^c decreases and e_g^c increases.*

Proof. Proofs for the results in this appendix are given at the end of this section. □

According to the above result, if decision making is centralized, the supply chain benefits from increasing good effort and reducing bad effort when reputation cost increases. This is expected because good effort allows the centralized firm to reduce operational risk without inflicting any harm on its reputation. This is particularly true in settings where there are no explicit cost advantages to choosing bad effort, which is the case in our model as we do not assume any cost disparities between the two efforts. Bad and good effort vary only in terms of how they affect the operational and reputation risk functions.

B.2 Deferred payment under limited liability

In this section, we study the role of deferred payments (as an alternative to penalties) in addressing process violations by a wealth-constrained supplier. Suppose that the buyer withholds a portion, $\gamma \in [0, 1]$, of the contract payment, T, which is forfeited if reputation risk materializes. This is equivalent to setting the penalty as $R_S = \gamma T$. In the absence of any limited liability, the multinational's problem includes only the supplier's individual rationality and incentive compatibility constraints. Specifically, the supplier's individual rationality constraint in this case is $(1 - \gamma F_M(\tilde{e_b}))T - F_S(\tilde{e_b}, \tilde{e_g})X_S - K - \tilde{e_b} - \tilde{e_g} \geq 0$. So when the supplier is not wealth-constrained, the buyer can retract the entire contract payment if reputation costs are high. This is because even if the forfeiture amount is set at its maximum, i.e. $\gamma^* = 1$, the supplier's individual rationality constraint can be satisfied by suitably adjusting the transfer payment.

However, if the supplier is protected by limited liability, the following constraint is added to the buyer's problem: $\Pi_S = (1 - \gamma)T - X_S - K - e_b - e_g \geq 0$. This means that for a wealth-constrained supplier, the transfer payment must be sufficiently high *and* the forfeiture penalty should be sufficiently low to ensure a non-negative profit in the worst-case. It is, therefore, clear that the buyer can no longer set the entire contract payment as the forfeiture penalty without violating the supplier's limited liability constraint (formally, $\gamma^* = 1 \implies \Pi_S < 0$).

Given that the supplier's limited liability constraint cannot be circumvented, the contractual parameters in a deferred payment contract (the transfer payment and the forfeiture amount) must be determined before production begins. Therefore, similar to a penalty contract, the forfeiture amount is capped when the supplier's net equity reaches zero. This indicates that under limited liability, deferred payments are not necessarily better than penalties in addressing supplier responsibility issues except that the former may be relatively easier to implement in practice.

B.3 Production cost and supplier violations

In this section, we extend our base model to include scenarios where supplier's bad effort reduces both operational risk and production cost. Recall that the supplier's production investment was denoted by $K \geq 0$. Suppose that by exerting bad effort, the supplier can reduce this production cost to $\phi(e_b)K$ where $\phi(e_b) \in [0, 1]$ is a decreasing convex function. We assume that $\phi(0) = 1$ and $\phi(\infty) = 0$ i.e., the supplier incurs full cost of production in the absence of any violation, and zero cost at infinite levels of bad effort. In this setting, how effective is a risk-sharing contract in addressing supplier responsibility issues?

We find that the results in Proposition 2 are largely robust to this extension, except that the threshold at which risk-sharing increases good effort is increased from Θ_2 to $\Theta_2 + \zeta$ where $\zeta \geq 0$. Specifically, we have the following result.

Proposition 7. *Define MRS, Θ_1, Θ_2 as before; and $\zeta = \frac{K\phi''(e_b)}{(1-\delta)X_S} / \frac{\partial^2 F_S(e_b,e_g)}{\partial e_b \partial e_g}$. Let the superscripts $\tilde{w}$ and $\tilde{r}$ represent a wholesale price contract and a risk-sharing contract under the "cost-and-risk" model, respectively. Then, the supplier's optimal efforts are related as follows.*

$$e_b^{\tilde{w}} < e_b^{\tilde{r}} \text{ and } e_g^{\tilde{w}} > e_g^{\tilde{r}}, \text{ if } MRS \leq \Theta_1$$
$$e_b^{\tilde{w}} > e_b^{\tilde{r}} \text{ and } e_g^{\tilde{w}} > e_g^{\tilde{r}}, \text{ if } MRS \in (\Theta_1, \Theta_2 + \zeta)$$
$$e_b^{\tilde{w}} > e_b^{\tilde{r}} \text{ and } e_g^{\tilde{w}} < e_g^{\tilde{r}}, \text{ if } MRS \geq \Theta_2 + \zeta$$

One might expect that when a noncomplying activity can reduce both risk and cost for the supplier, a risk-sharing contract would be less likely to prevent violations. In our model, this would mean that the threshold for reducing bad effort is higher. But we find that the condition for risk-sharing to reduce bad effort (MRS $> \Theta_1$) remains unchanged. And in fact, risk-sharing is more likely to reduce good effort in this extended model. Recall that good effort only reduces operational risk and has no impact on production cost.[17] When violations facilitate both risk mitigation and cost reduction, the supplier may respond to a risk-sharing contract by decreasing good effort *by a greater amount* than bad effort. This strategy allows the supplier to reap the full benefit of risk-sharing without heavily compromising on cost savings achieved by bad effort. This explains why, for MRS $\in [\Theta_2, \Theta_2 + \zeta)$, risk-sharing continues to decrease good effort in the extended model. But

[17] We make this assumption because there is little evidence in practice of good effort affecting production costs. Of course, good effort itself may be more expensive than bad effort in that better hygiene or more probiotics may be needed to maintain animal health. This effect is captured in our model as the dollar value of exerting good effort. As such, any adverse impact of good effort on the costs of raising livestock, for example through slower animal growth rate, is limited. Consider, for instance, countries where farm antibiotics use was restricted and meat producers were compelled to switch to more sustainable methods. Public health researchers found no significant negative impact of these regulations (McEwen et al., 2018).

when violations have no impact on production cost, it increases good effort for MRS $\geq \Theta_2$ (as shown in Proposition 2).

B.4 Role of supplier's net equity

Our base model assumes that the supplier must earn a non-negative profit in the worst-case scenario. In this subsection, we explore the role of a risk-sharing contract when this condition is relaxed. Specifically, suppose that the supplier could go insolvent under the contract but its maximum loss must be capped at a general net equity level E. That is, the supplier's limited liability constraint is given by $T - (1-\delta)X_S - K - e_b - e_g \geq -E$.

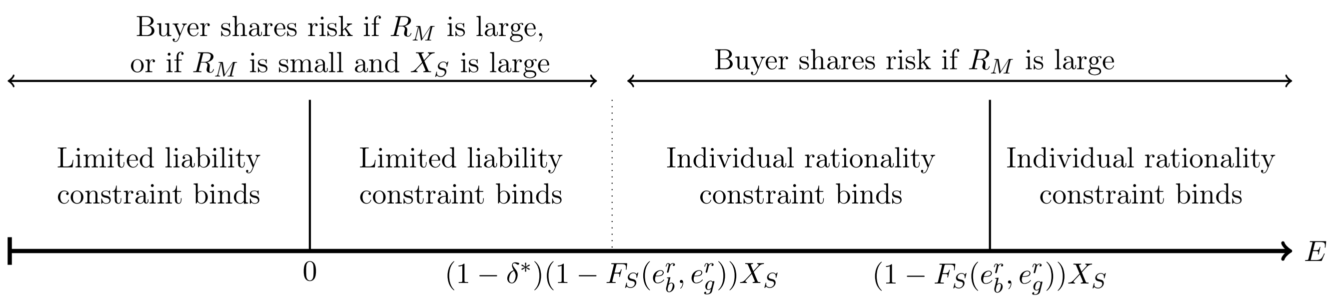


Figure 6: The role of supplier's net equity

We find that, in this generalization, the value of E determines whether or not the limited liability constraint binds. For instance, $E \leq 0$ means that the supplier is severely wealth constrained and must earn at least a non-negative profit in the worst-possible outcome of the contract. In this case, limited liability constraint binds and the result from Proposition 3 continues to hold. If risk-sharing reduces bad effort, the buyer benefits through a lower reputation risk. And even if bad effort increases, risk-sharing can be valuable as it allows the buyer to reduce the transfer payment by limiting worst-case liability compensation to the supplier.

In contrast, when the supplier can withstand large losses, a risk-sharing contract is no longer beneficial for the multinational if it increases bad effort. This is because at high values of net equity, specifically for $E > (1 - F_S(e_b^r, e_g^r))X_S$, the supplier's limited liability constraint becomes non-binding and only the participation constraint binds at optimality. Consequently, the reduction in worst-case liability payment achieved by risk-sharing ceases to be of any value to the multinational as the supplier only has to be compensated for its reservation level of expected profit. The following result characterizes the condition for offering a risk-sharing contract in this case.

Proposition 8. *If* $E > (1 - F_S(e_b^r, e_g^r))X_S$*, then the multinational shares supplier's risk if* $R_M \frac{dF_M(e_b^r)}{de_b} \frac{\partial e_b^r}{\partial \delta}\Big|_{\delta=0} < \frac{X_M}{X_S} \frac{\partial (e_b^r + e_g^r)}{\partial \delta}\Big|_{\delta=0}$.

Recall from Proposition 2(i) that risk-sharing suppresses the sum of bad and good effort. So the expression on the right of the above inequality is negative (because $X_M > 0, X_S > 0$, and $\partial(e_b^r + e_g^r)/\partial\delta\big|_{\delta=0} < 0$). If the inequality holds, the expression on the left must also be negative. As $R_M > 0$, this means that risk-sharing must suppress bad effort i.e., $\partial e_b^r/\partial\delta\big|_{\delta=0} < 0$. In other words, when the supplier has enough net equity, a necessary condition for the buyer to offer risk-sharing is that it must reduce violations. In addition, when $\partial e_b^r/\partial\delta\big|_{\delta=0} < 0$, the condition in Proposition 8 implies that R_M must be above a certain threshold for the buyer to offer risk-sharing. Therefore, the buyer will share the supplier's risk only when its reputation costs are high enough.

A final possibility is when the supplier is not severely wealth-constrained and neither does it have large cash reserves. In this case, it is not possible to explicitly determine which of the two constraints – limited liability or individual rationality – will bind. This is because the binding constraint depends endogenously on the optimal level of coverage offered by the multinational. In particular, the participation constraint is tight if $E > (1-\delta^*)(1-F_S(e_b^r, e_g^r))X_S$; otherwise limited liability binds. But the main intuition remains the same in that the benefit to the buyer from a risk-sharing contract is contingent on the binding constraint. Figure 6 illustrates this discussion.

Proofs for Additional Results

Proof of Lemma B1. Note that the choice set for the centralized firm's problem, $[0,\infty)\times[0,\infty)$, is defined on a lattice with the component-wise order: $\mathbf{x} \geq \mathbf{y}$ if and only if $x_i \geq y_i$ for all i. Also, $\frac{\partial^2 E\Pi_C}{\partial e_g \partial e_b} = -\frac{\partial^2 F_S(e_b,e_g)}{\partial e_g \partial e_b}(X_S + X_M) < 0$ i.e., the objective function for the centralized supply chain, $E\Pi_C$, is supermodular in $(e_g, -e_b)$. We can also verify that the objective has increasing differences in $(e_g, -e_b, R_M)$ as $\frac{\partial^2 E\Pi_C}{\partial e_g \partial e_b} < 0$, $\frac{\partial^2 E\Pi_C}{\partial R_M \partial e_g} = 0$, and $\frac{\partial^2 E\Pi_C}{\partial R_M \partial e_b} = -\frac{dF_M(e_b)}{de_b} < 0$. Therefore, by Topkis's monotonicity theorem (Topkis, 1978), e_b^c is (weakly) decreasing in R_M and e_g^c is (weakly) increasing in R_M. $\square$

Proof of Proposition 7. The proof for this proposition is analogous to the proof of Proposition 3. This is because we again need to examine the impact of change in risk-coverage, δ, on the optimal efforts. Further, the supplier's objective function under the extended model is concave because both $\phi(e_b)$ and $F_S(e_b, e_g)$ are convex functions. Therefore, the supplier's first order necessary conditions are also sufficient and we can use the implicit function theorem. Differentiating the first order conditions with respect to δ, we get

$$\underbrace{\begin{bmatrix} -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b^2}(e_b^{\tilde{r}},e_g^{\tilde{r}}) - K\phi''(e_b^{\tilde{r}}) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \\ -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_g^2}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \end{bmatrix}}_{\mathbf{H}} \begin{bmatrix} \frac{\partial e_b^{\tilde{r}}}{\partial \delta} \\ \frac{\partial e_g^{\tilde{r}}}{\partial \delta} \end{bmatrix} = \begin{bmatrix} -X_S\frac{\partial F_S}{\partial e_b}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \\ -X_S\frac{\partial F_S}{\partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \end{bmatrix}$$

Now $det(H) = (1-\delta)^2X_s^2\left(\frac{\partial^2 F_S}{\partial e_b^2}(e_b^{\tilde{r}},e_g^{\tilde{r}})\frac{\partial^2 F_S}{\partial e_g^2(e_b^{\tilde{r}},e_g^{\tilde{r}})} - (\frac{\partial^2 F_S}{\partial e_b \partial e_g})^2(e_b^{\tilde{r}},e_g^{\tilde{r}})\right) + (1-\delta)X_S\frac{\partial^2 F_S}{\partial e_g^2}(e_b^{\tilde{r}},e_g^{\tilde{r}})K\phi''(e_b^{\tilde{r}})$. Recall that $F_S(e_b,e_g)$ and $\phi(e_b)$ are convex functions. Convexity of $F_S(e_b,e_g)$ implies that its hessian matrix is positive semi-definite. For ease of analysis, we restrict our attention to those functions, $F_S(e_b,e_g)$, whose hessian matrix is positive definite for all effort levels. This means that $\frac{\partial^2 F_S}{\partial e_b^2}\frac{\partial^2 F_S}{\partial e_g^2} > (\frac{\partial^2 F_S}{\partial e_b \partial e_g})^2$ for all $e_b, e_g \geq 0$. And therefore, $det(H) > 0$. Using Cramer's rule, we can solve the above system of equations to get

$$\frac{\partial e_b^{\tilde{r}}}{\partial \delta} = \frac{1}{det(H)}\underbrace{\begin{vmatrix} -X_S\frac{\partial F_S}{\partial e_b}(e_b^{\tilde{r}},e_g^{\tilde{r}}) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \\ -X_S\frac{\partial F_S}{\partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) & -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_g^2}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \end{vmatrix}}_{J_{e_b}} \text{ and} \tag{3}$$

$$\frac{\partial e_g^{\tilde{r}}}{\partial \delta} = \frac{1}{det(H)}\underbrace{\begin{vmatrix} -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b^2}(e_b^{\tilde{r}},e_g^{\tilde{r}}) - K\phi''(e_b^{\tilde{r}}) & -X_S\frac{\partial F_S}{\partial e_b}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \\ -(1-\delta)X_S\frac{\partial^2 F_S}{\partial e_b \partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) & -X_S\frac{\partial F_S}{\partial e_g}(e_b^{\tilde{r}},e_g^{\tilde{r}}) \end{vmatrix}}_{J_{e_g}} \tag{4}$$

As $det(H) > 0$, the sign of $\frac{\partial e_b^{\tilde{r}}}{\partial \delta}$ and $\frac{\partial e_g^{\tilde{r}}}{\partial \delta}$ depends on the sign of determinants J_{e_b} and J_{e_g}, respectively. Specifically, we have $\frac{\partial e_b^{\tilde{r}}}{\partial \delta} < 0$ if MRS $> \Theta_1$ for all (e_b, e_g); where MRS $= \frac{\partial F_S}{\partial e_b}/\frac{\partial F_S}{\partial e_g}$ and $\Theta_1 = \frac{\partial^2 F_S}{\partial e_b \partial e_g}/\frac{\partial^2 F_S}{\partial e_g^2}$. And $\frac{\partial e_g^{\tilde{r}}}{\partial \delta} < 0$ if MRS $< \Theta_2 + \zeta$ for all (e_b, e_g); where $\Theta_2 = \frac{\partial^2 F_S}{\partial e_b^2}/\frac{\partial^2 F_S}{\partial e_b \partial e_g}$ and $\zeta = \frac{X_s K\phi''(e_b)}{(1-\delta)X_s^2}/\frac{\partial^2 F_s}{\partial e_b \partial e_g}$. □

Proof of Proposition 8. With a general net equity level, the supplier's limited liability constraint under risk-sharing is $T - (1-\delta)X_S - K - e_b^r - e_g^r \geq -E$. Suppose that $E > (1 - F_S(e_b^r, e_g^r))X_S$ and that the limited liability constraint binds at optimality. Then, the individual rationality constraint is violated because

$$\begin{aligned} T^* &= -E + (1-\delta^*)X_S + K + e_b^r + e_g^r \\ &< -(1 - F_S(e_b^r, e_g^r))X_S + (1-\delta^*)X_S + K + e_b^r + e_g^r \\ &\leq -(1-\delta^*)(1 - F_S(e_b^r, e_g^r))X_S + (1-\delta^*)X_S + K + e_b^r + e_g^r \\ &= F_S(e_b^r, e_g^r)(1-\delta^*)X_S + K + e_b^r + e_g^r \end{aligned}$$

Therefore, the individual rationality constraint must bind at optimality when $E \geq (1-F_S(e_b^r, e_g^r))X_S$ and we can verify that the limited liability constraint will be satisfied. Substituting the value of T^* from the participation constraint into the buyer's objective function, and proceeding exactly as in the proof of Proposition 3, we get the required result. □