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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 such as dual sourcing mitigate the buyer's operational risk, but they 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 such as 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.

1. Introduction

Multinationals are increasingly facing *reputation risk* as a result of their suppliers' actions, which may violate the buyer's social and environmental standards. This risk, which is amplified as a result of nongovernmental organization (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 nontherapeutic reasons such as disease prevention and growth promotion. Using antibiotics allows farmers to both (1) reduce their operational risk of having a low yield and (2) reduce their cost of production, because animals on antibiotics typically consume less feed to reach the desired weight.

In this paper, we focus primarily on the supplier's risk-mitigation actions that could have a negative externality on the buyer. In Section 7.2, however, 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 that make them susceptible to diseases without the use of antibiotics. Disease outbreaks can cause significant losses. The H1N1 outbreak, for instance, cost U.S. 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 United States. 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 United States 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, which 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 U.S. fast-food restaurant chains on the antibiotics practices of their suppliers, with the goal of identifying the worst offenders (Stashwick et al. 2016).

Policymakers are also tightening regulations to safeguard against the growing threat of antimicrobial resistance. For example, recent U.S. Food and Drug Administration guidelines mandate veterinary prescriptions 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 United States 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 Initiative 2016).

Resolving the issue of supplier responsibility is challenging for these multinational food companies because they face a twin threat. On the 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. 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 because 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—that is, 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 to our knowledge, 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 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, by contrast, strong public-private partnerships and intense research programs have developed vaccines and other sustainable techniques for managing fish health that have enabled their salmon producers to sharply curtail dependence on antibiotics (Einen 2013).

This 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 toward 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 toward using more good effort. By contrast, 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 counterintuitive 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 nonnegative profit under all conditions, the buyer has to set the contract payment high enough to cover the entire operational loss of the supplier. By covering some of this loss (ex ante) through risk sharing, though, 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. Despite these lower risks under a penalty, however, 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 that the supplier does not incur a loss in the event the maximum penalty is charged. In reality, the supplier only pays a penalty in expectation—that is, *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—for example, Babich and Tang (2012) and Chen and Lee (2017)—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 nontrivial 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.

2.1. Environmental and Social Responsibility in Supply Chains
Ensuring supply chain social and environmental responsibility has become an increasingly vexing issue for firms that 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; Caro et al. (2018), Chen et al. (2020a), and Fang and Cho (2020) who study supplier audits in different multifirm 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. In recent years, though, 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 the responsibility level. Short et al. (2016) and Chen et al. (2020b) 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. 2018, Chen et al. 2019, Kalkanci and Plambeck 2020), 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). Although 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 offshore 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. Furthermore, 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. By contrast, in our model, the supplier chooses bad and good effort simultaneously, and both 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 damage, but in our model, the reputation damage from bad effort accrues only to the buyer.

2.2. Risk-Sharing and Performance-Based Contracts

Risk-sharing contracts have been studied in the operations management (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). By 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 finally, they consider a risk-averse agent, whereas 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. Unlike their model, though, we consider risk sharing as an instrument to mitigate reputation risk

for the buyer in a multifirm setting. Insurance contracts under moral hazard have also been studied extensively 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. By contrast, our model considers risk-neutral players and moral hazard on the part of an agent whose risk is shared by the principal. Furthermore, the aforementioned papers consider third-party insurance schemes, but in our model, risk coverage is embedded in the contract offered to the agent.

Because this paper is motivated by reputation risk in food supply chains, our work also contributes to the literature on 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. For 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 (PBCs) in principal-agent models. Prior studies in OM have considered PBCs to improve product reliability in after-sales support (see, e.g., Kim et al. 2007, 2010; 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 (1) a cost-reduction effort and (2) 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 efforts are strategic substitutes, and *both* reduce operational risk in the supply chain. Furthermore, Kim et al. (2007) consider multiple risk-averse agents, whereas we study a single risk-neutral agent with limited liability. More important, their focus is on improving after-sales service of capital-intensive products, whereas 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 because of 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 whether 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, p. 2795) 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 efforts exerted by the supplier, respectively, where e_b and e_g, respectively, 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 on account of 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); that is, as good effort increases, the

marginal decrease in risk (the absolute value of the risk reduction) as a result of 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. Furthermore, any difference between the cost of bad and good efforts 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 costs 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 United States and increased the wholesale price of chicken eggs by 84.5% (*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 (Fitzpatrick 2015, Strom 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 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, which 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 as a result of contractual obligations (Sappington 1983). This is reasonable for a cash-strapped supplier that may renege on the contract if the transfer payment is too low. The supplier decides whether to accept the offer based on its expected payoff. Once the contract is accepted, the supplier exerts bad and good efforts to mitigate operational risk. Finally, the buying firm incurs an expected reputation loss that 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 farmers and the food companies. Advantages for farmers include protection from crop price volatility and difficulty in finding buyers on commodity spot markets. Buying firms can also benefit by specifying input requirements (such as use of certified seed providers) to farmers. As Federgruen et al. (2019, p. 362) 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 efforts under a wholesale price contract, respectively. Then the multinational firm chooses the transfer payment to minimize its operational and reputation risks subject to the supplier's ex post limited liability. The firm's problem is formulated as follows:

$$\max_{T \geq 0} E\Pi_M = V - T - F_S(e_b^w, e_g^w)X_M - F_M(e_b^w)R_M$$

$$\text{subject to} \quad T - X_S - K - e_g^w - e_b^w \geq 0,$$
$$T - F_S(e_b^w, e_g^w)X_S - K - e_g^w - e_b^w \geq 0,$$
$$(e_b^w, e_g^w) \in \arg\max_{e_b, e_g \geq 0} T - F_S(e_b, e_g)X_S$$
$$- K - e_g - e_b, E\Pi_M \geq 0.$$

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 nonbinding and can be removed (because if it were binding, the 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, respectively).

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 Online Appendix A.

When the marginal increase in reputation risk is above a certain threshold, the supplier exerts more bad effort and less 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 lesser good effort than the centralized firm. This result is not surprising because 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 efforts under a risk-sharing contract, respectively. Then the multinational firm chooses the transfer payment and the coverage level to minimize

its operational and reputation risk, and it solves the following:

$$\max_{T \geq 0, \delta \in [0,1)} E\Pi_M = V - T - F_S\left(e_b^r, e_g^r\right)(X_M + \delta X_S) - F_M(e_b^r)R_M$$

$$\text{subject to} \quad T - (1-\delta)X_S - K - e_g^r - e_b^r \geq 0,$$

$$T - F_S\left(e_b^r, e_g^r\right)(1-\delta)X_S - K - e_g^r - e_b^r \geq 0,$$

$$\left(e_b^r, e_g^r\right) \in \underset{e_b, e_g \geq 0}{\arg\max} \ T$$

$$- F_S\left(e_b, e_g\right)(1-\delta)X_S - K - e_b - e_g,$$

$$E\Pi_M \geq 0.$$

Let (T^*, δ^*) denote the optimal solution to the above-mentioned problem. As in the case of the wholesale price contract, the limited-liability constraint binds at optimality, and we can remove the participation constraint because it is nonbinding. Note, however, that risk sharing makes the limited-liability constraint weaker for the firm because 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 efforts (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, this condition means that good effort is relatively less effective at reducing 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 efforts 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 as a result of weak regulatory enforcement. Such a supplier may gravitate toward bad effort to manage operational risk rather than good effort when the potential loss as a result of operational risk is enormous. However, if this loss is reduced through risk sharing, the supplier may be persuaded to shift away from bad effort toward using more good effort. By contrast, 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 toward 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 kilograms of antibiotics. By contrast, that same year, Chile produced 750,000 tonnes of salmon using more than 450,000 kilograms of antibiotics. And in 2014, Chilean salmon farms increased their consumption of antibiotics by 25% to 563,200 kilograms for producing 895,000 tonnes of fish (Terazono 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). By 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 toward bad effort rather than good effort when the potential loss as a result of operational risk is large. But if this loss is reduced through risk sharing, the supplier may be persuaded to shift away from bad effort toward using more good effort. By contrast, a supplier such as a Norwegian salmon producer inclines toward 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 toward 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 efforts. The following proposition summarizes the earlier 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 a wholesale price contract and a risk-sharing contract is characterized as follows:*

   a. $e_b^w + e_g^w > e_b^r + e_g^r$, *and*

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

Note first from Proposition 2(a) that risk sharing always suppresses total effort by the supplier (i.e., the sum of bad and good efforts) because 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 efforts. As Proposition 2(b) shows, however, 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 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 1(a) 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 efforts, and it is implicitly determined by the solution to the supplier's problem.

From Proposition 2(a), we know that risk sharing reduces total effort and shifts the budget line downward. We argue that any point on the lower indifference curve that lies to the left of point B cannot be the point of tangency for this new budget line. Suppose for a moment that point 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
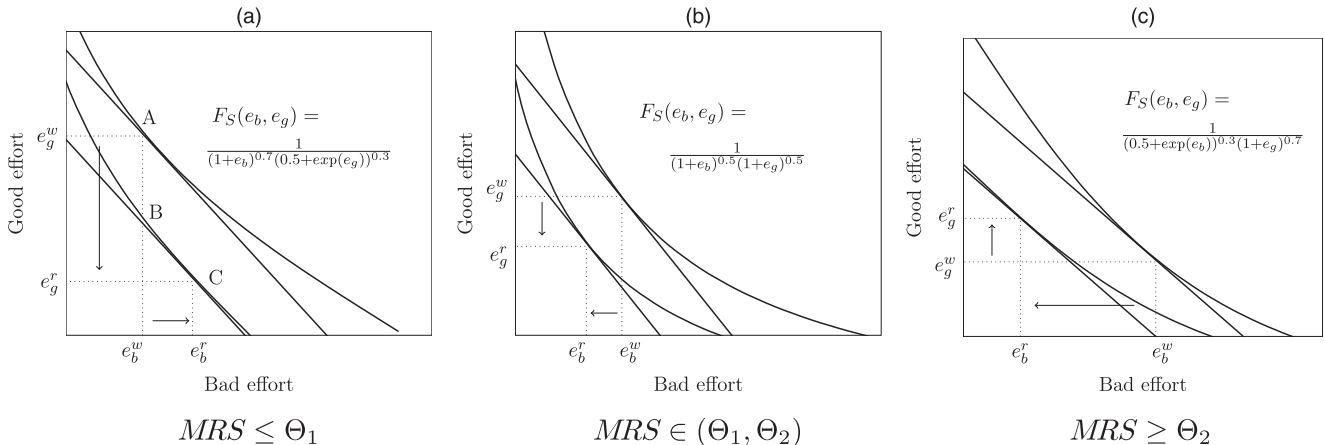
is the optimal point for wholesale price contract). But as the slope is decreasing in good effort, the slope of the curve at point B is, in fact, greater than the slope at point A. Furthermore, because the indifference curves are convex to the origin, any point to the left of B will have a higher slope than the slope at B. Hence, the point of tangency must lie to the right of B; that is, 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 that MRS $\in (\Theta_1, \Theta_2)$ is equivalent to the slope decreasing in bad effort but increasing in good effort. Using arguments analogous to these, 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 efforts when MRS $\in (\Theta_1, \Theta_2)$. Figure 1 illustrates each of these possibilities.

This 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 whether 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 $F'_M(e_b^r)(\partial e_b^r / \partial \delta)|_{\delta=0} R_M < u(X_S, X_M, 0)$. The threshold is increasing in X_S and decreasing in X_M.*

This 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 implications. The first is when risk sharing reduces bad effort (i.e., when $(\partial e_b^r / \partial \delta)|_{\delta=0} < 0$). Recall from Proposition 2 that this condition is equivalent to MRS $> \Theta_1$. Rearranging the terms in the above-mentioned condition implies that R_M must be above a certain threshold for the firm to offer risk sharing. In other words, the firm can

Figure 1. Supplier's Efforts Under a Risk-Sharing Contract vs. Wholesale Price Contract

(a)

$F_S(e_b, e_g) = \frac{1}{(1+e_b)^{0.7}(0.5+\exp(e_g))^{0.3}}$

$MRS \leq \Theta_1$

(b)

$F_S(e_b, e_g) = \frac{1}{(1+e_b)^{0.5}(1+e_g)^{0.5}}$

$MRS \in (\Theta_1, \Theta_2)$

(c)

$F_S(e_b, e_g) = \frac{1}{(0.5+\exp(e_b))^{0.3}(1+e_g)^{0.7}}$

$MRS \geq \Theta_2$

strategically use risk sharing to suppress the 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 2(a)).

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 which 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 United States 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 $(\partial e_b^r / \partial \delta)|_{\delta=0} > 0$ 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. Because 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
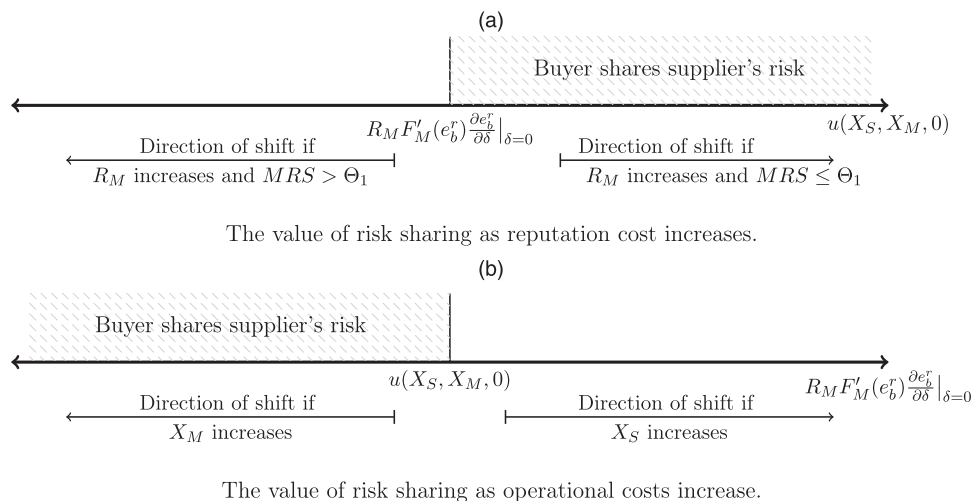
operational loss. So, when the supplier's operational loss is high and the firm's reputation loss is low, it can use risk sharing (despite an increase in bad effort) to put a cap on the transfer payment to a wealth-constrained supplier. This suggests that even if risk sharing worsens social welfare, 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-sharing agreement cancels out in the buyer's expected profit. Thus, when bad effort increases, the buyer has no incentive to share the supplier's risk because both operational and reputation risks 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.

Furthermore, 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. By contrast, the buyer's preference for risk sharing decreases 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 2(b) for an illustration.

So far we have established that (1) risk sharing can increase or decrease the supplier's bad effort, and (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.

Figure 2. Buyer's Decision to Offer Risk Sharing as a Function of Operational and Reputation Costs

(a)

Buyer shares supplier's risk

$R_M F_M'(e_b^r) \frac{\partial e_b^r}{\partial \delta}|_{\delta=0}$ $u(X_S, X_M, 0)$

Direction of shift if R_M increases and MRS $> \Theta_1$

Direction of shift if R_M increases and MRS $\leq \Theta_1$

The value of risk sharing as reputation cost increases.

(b)

Buyer shares supplier's risk

$u(X_S, X_M, 0)$ $R_M F_M'(e_b^r) \frac{\partial e_b^r}{\partial \delta}|_{\delta=0}$

Direction of shift if X_M increases

Direction of shift if X_S increases

The value of risk sharing as operational costs increase.

Proposition 4. *The bounds on the optimal coverage level δ^* are obtained as follows: $\delta^* \leq (\frac{X_S - X_M}{2X_S})^+$ if $MRS \leq \Theta_1$ and $R_M \gg X_S$, and $\delta^* \geq (\frac{X_S - X_M}{2X_S})^+$ 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 important, 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 (because of a weakened limited-liability constraint). But when X_S is small in comparison with both X_M and R_M, the buyer is better off without sharing the supplier's risk. By contrast, 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. Because the supplier is protected by limited liability, however, 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, although theoretically possible, transferring all the 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 the supplier's bad effort and increases good effort in comparison with 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 because the supplier is wealth constrained and hence does not bear the full cost of reputation damage. Specifically, the maximum penalty is capped when the supplier's net equity reaches zero. This can be seen from the multinational firm's problem, which is given by

$$\max_{T, R_S \geq 0} E\Pi_M = V - T - F_S\left(e_b^p, e_g^p\right)X_M - F_M\left(e_b^p\right)(R_M - R_S)$$

$$\text{subject to} \quad T - X_S - R_S - K - e_g^p - e_b^p \geq 0,$$

$$T - F_S\left(e_b^p, e_g^p\right)X_S - F_M\left(e_b^p\right)R_S - K - e_g^p - e_b^p \geq 0,$$

$$\left(e_b^p, e_g^p\right) \in \underset{e_b, e_g \geq 0}{\operatorname{argmax}} \, T - F_S\left(e_b, e_g\right)X_S$$

$$- F_M(e_b)R_S - K - e_b - e_g,$$

$$E\Pi_M \geq 0.$$

Let (T^*, R_S^*) denote the solution to the above-mentioned problem. The limited-liability constraint needs to compensate the supplier in the worst case (i.e., when it has to bear the reputation penalty). Because 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 a supplier's moral hazard. By contrast, Chen and Lee (2017) study a variant of the deferred payment mechanism to address process violations occurring as a result of adverse selection. In Section B.2 of Online Appendix B, we study the role of deferred payments to address process violations that may arise as a result of 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 re-solving supplier responsibility issues.

6. Risk-Sharing vs. Penalty Contract

The previously described analysis shows that relative to a wholesale price contract, imposing a penalty on the supplier (1) reduces bad effort, (2) increases good effort, and (3) increases the transfer payment (because of limited liability). By contrast, risk sharing may increase or decrease the supplier's bad and good efforts, and it 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:*

a. $e_b^p + e_g^p > e_b^w + e_g^w > e_b^r + e_g^r$, and
b. $e_b^p < e_b^w < e_b^r$ if $MRS \le \Theta_1$, and $e_g^p > e_g^w > e_g^r$ if $MRS \le \Theta_2$.

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

We find that the sum of bad and good efforts is always the highest under a penalty contract. When $MRS \le \Theta_1$, a 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 depends 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(a)). The ranking of efforts in this case 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(a)) that the total effort is the highest under a penalty. By contrast, a penalty leads to a lower reputation risk than risk sharing if $MRS \le \Theta_1$. For $MRS > \Theta_1$, reputation risk under a penalty contract may be greater or lesser than that under risk sharing. This is because when $MRS > \Theta_1$, both risk sharing and penalty reduce bad effort, and the magnitude

of the decrease is determined by the optimal contract terms.

To summarize, a penalty is better than risk sharing for reducing both operational and reputation risks if $MRS \le \Theta_1$. Then should the buyer consider risk sharing in this case? Recall that risk sharing weakens the limited-liability constraint because 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 the 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, respectively. 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:

$$E\Pi_M^r = V - (1 - \delta^*)X_S - K - e_b^r - e_g^r - (X_M + \delta^* X_S)F_S(e_b^r, e_g^r)$$
$$- F_M(e_b^r)R_M,$$
$$E\Pi_M^p = V - X_S - R_S^* - K - e_b^p - e_g^p - F_S(e_b^p, e_g^p)X_M$$
$$- F_M(e_b^p)(R_M - R_S^*).$$

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

$$\Delta = \underbrace{\begin{array}{c} (1 - F_M(e_b^p))R_S^* + (1 - F_S(e_b^r, e_g^r))\delta^* X_S \\ + (e_b + e_g)^p - (e_b + e_g)^r \end{array}}_{\ge 0 \text{ using Proposition 6(a)}}$$
$$+ \underbrace{(F_M(e_b^p) - F_M(e_b^r))}_{\le 0 \text{ if } MRS \le \Theta_1} R_M.$$

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 a risk-sharing contrast 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.

Figure 3. Comparison of the Three Contracts When $MRS \le \Theta_1$
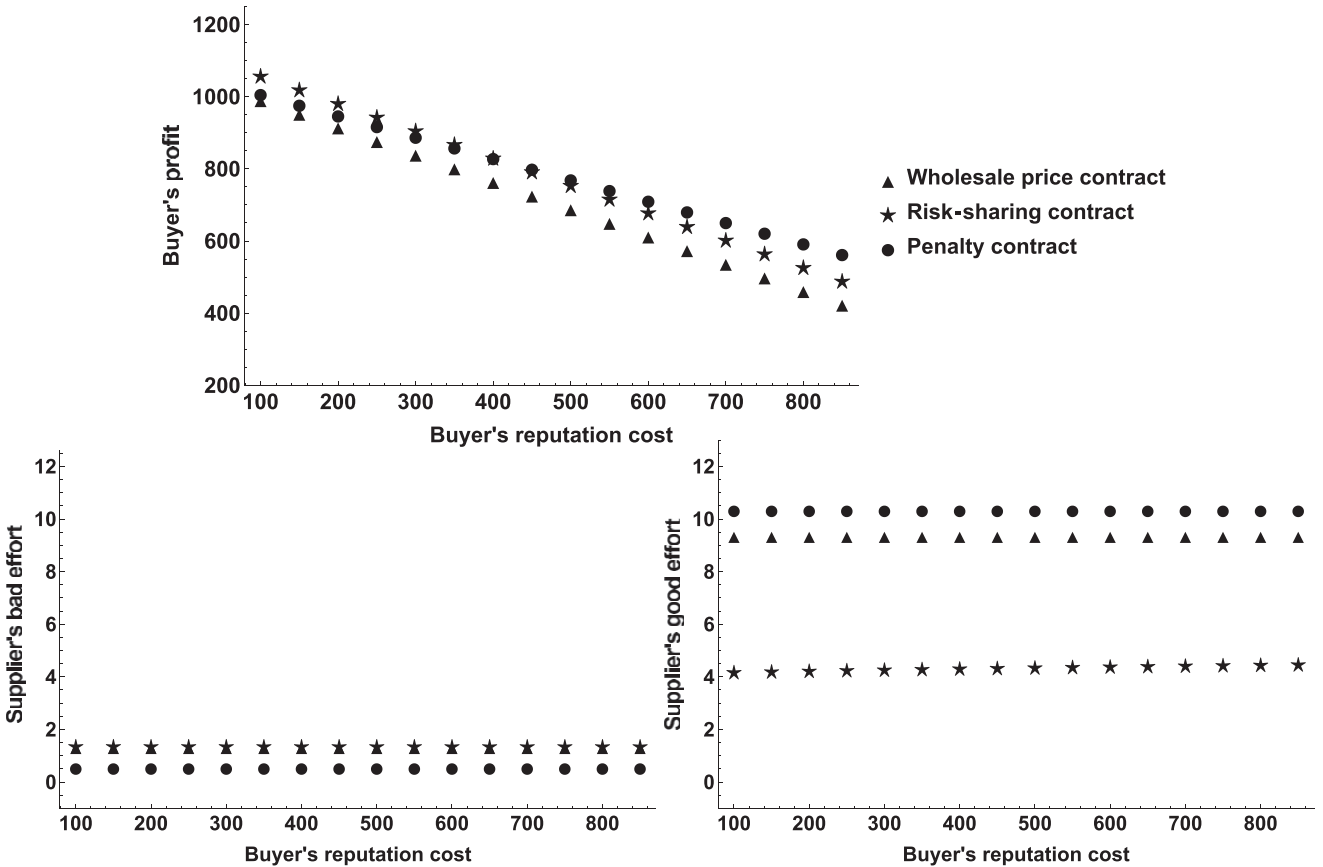
$X_M = 50$, $X_S = 100$, $K = 20$, $V = 1200$, $F_S(e_b, e_g) = 1/((1+e_b)^{0.7}(0.5 + \exp(e_g))^{0.3})$, $F_M(e_b) = e_b^{0.5}/(1+e_b)^{0.5}$

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 a 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 because of 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
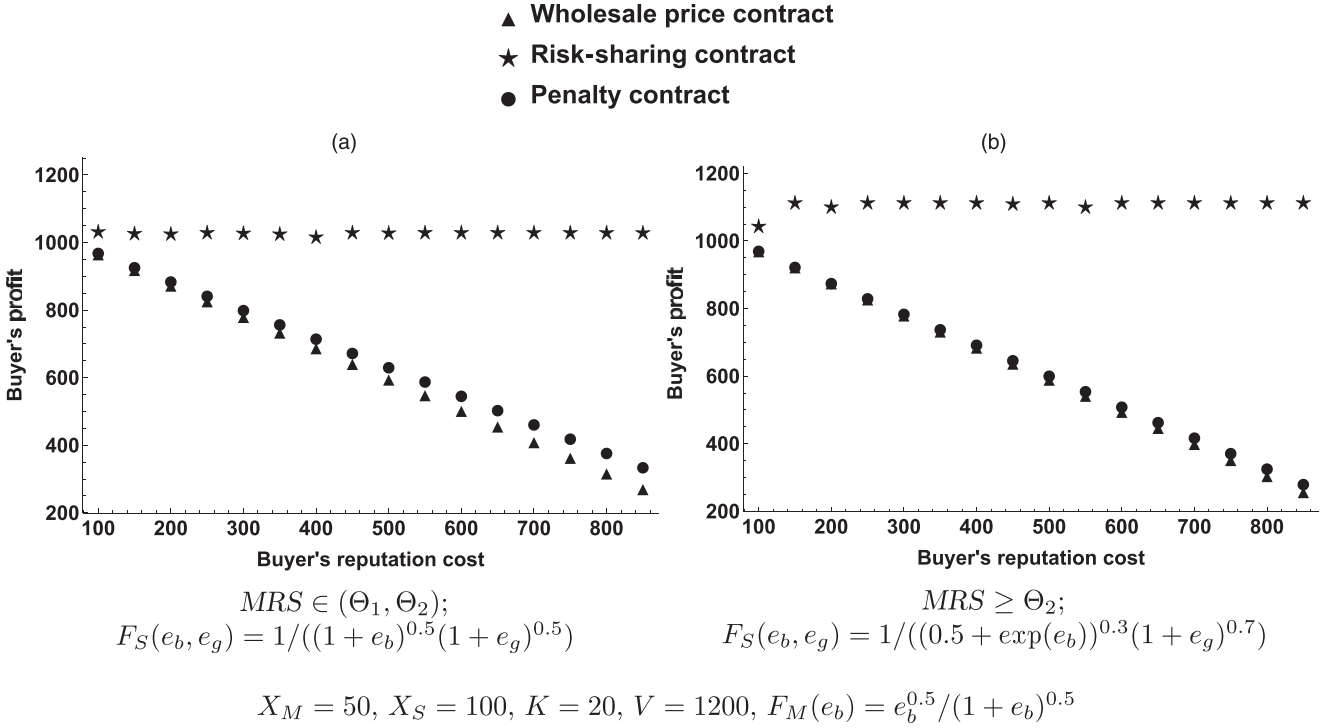
supplier's bad effort to zero. As a result, the buyer faces no negative externality with an increase in reputation cost.

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 (1) the buyer imposes a penalty to transfer a part of its reputation damage to the supplier, and (2) risk coverage that transfers part of the supplier's operational damage to the buyer is provided.

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 because of 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. Thus, unless

Figure 4. Buyer's Profit Under the Three Contracts When $MRS > \Theta_1$

▲ **Wholesale price contract**
★ **Risk-sharing contract**
● **Penalty contract**

(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)

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

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

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.

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 suboptimal when reputation is a serious concern because 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 that provide quantities q_A and q_B, respectively. The buyer can either (1) split the single-source order quantity (of one unit) between the two suppliers (to hedge against operational risk at any one supplier) or (2) 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
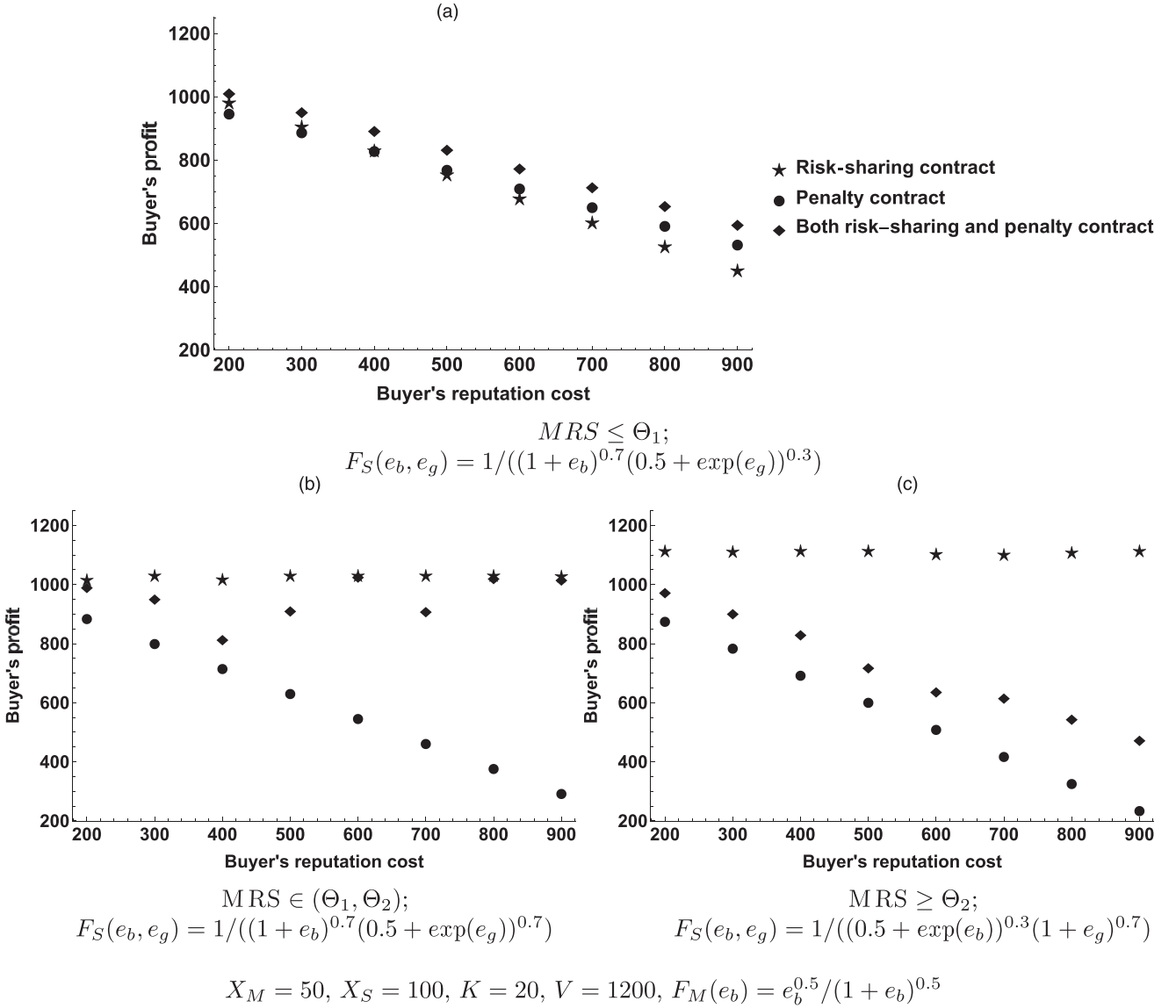
extreme, the buyer sources twice the order quantity it needs—one unit from *each* supplier.

Each supplier exerts bad and good efforts 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 because production capacities can be transferred between the suppliers. For instance, if an 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 suppliers, 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 that the buyer procures 0.6 unit from each supplier, and risk materializes for supplier A. In this case, the buyer incurs *less than* 40% of the total operational loss because (1) supplier B provides 0.6 unit, and (2) 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

Figure 5. Risk Sharing and Penalty vs. the Composite Contract

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

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

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

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

buyer's operational loss distribution can be written as follows:

Multinational's operational loss

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

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 $-R_M \ F_{M,A}^2 + 2R_MF_{M,A} > -R_MF_{M,A} + 2R_MF_{M,A} = R_MF_{M,A}$, which is its expected reputation loss under single sourcing.

From this 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:

$$\max_{T,q_A,q_B \geq 0} E\Pi_{M,D} = V - (q_A + q_B)T - 2cX_M F_{S,A}$$
$$- X_M F_{S,A}^2(1-2c) - 2R_M F_{M,A} + R_M F_{M,A}^2$$

subject to
$$q_i T \quad - X_S - q_i K - e_{b,i} - e_{g,i} \geq 0, \text{ for } i \in \{A,B\},$$
$$q_i T \quad - F_{S,i}X_S - q_i K - e_{b,i} - e_{g,i} \geq 0,$$
$$\text{for } i \in \{A,B\},$$
$$(e_{b,i}, e_{g,i}) \in \underset{e_b,e_g \geq 0}{\arg\max} \, q_i T - F_{S,i}X_S - q_i K - e_{b,i} - e_{g,i},$$
$$\text{for } i \in \{A,B\},$$
$$\sum_{i \in \{A,B\}} q_i \in [1,2]; E\Pi_{M,D} \geq 0.$$

Because the limited-liability constraints bind at optimality, we have $(q_A + q_B)T^* = 2X_S + (q_A + q_B)K + e_{b,A}^* + e_{g,A}^* + e_{b,B}^* + e_{g,B}^*$. 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:

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

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

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

It is clear from these expressions 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 ($X_M \to 0$) because $E\Pi_{M,D} - E\Pi_{M,S} < 0$.

7.1.1. Risk Sharing vs. Dual Sourcing.
In the preceding analysis, we show how dual sourcing can exacerbate the buyer's reputation cost in comparison with 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 preceding section, dual sourcing always decreases the buyer's operational cost but increases reputation and sourcing costs. By contrast, 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 the transfer payment will be higher under dual sourcing (see Table 1 for a summary).

This indicates that the two mechanisms do not play a complementary role in the buyer's risk-management tool kit. 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. For a consumer facing a buyer whose reputation cost can be quite large, however, 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 because it can substantially increase their time to recovery (Sheffi 2015). Large consumer-facing companies, by contrast, 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 2018). 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

Table 1. Risk Sharing and Dual Sourcing Relative to Single Sourcing with Wholesale Price

Strategy	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

buyer and reputation costs are not that high. By 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 noncompliant action. Consider, for instance, the case of antibiotics usage in farming. Although the primary motive may be to stave off diseases, using antibiotics also accelerates animal growth rate so that the livestock reach the 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 a 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 Section B.3 of Online Appendix B.

7.3. Role of Supplier's Net Equity

Our model thus far assumes that the supplier must earn a nonnegative profit in the worst-case scenario. In Section B.4 of Online Appendix B, 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. Because the value of E determines whether the limited-liability constraint binds, the result from Proposition 3 continues to hold when $E \leq 0$. By contrast, when the supplier can withstand large losses ($E > 0$), a risk-sharing contract may no longer be beneficial for the buyer. For details, see Section B.4 of Online Appendix B.

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 either practitioners or researchers. 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 nontrivial implications of risk sharing in multitask 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 cannot directly observe or control these efforts. Both bad and good efforts 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 efforts. 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 implications of risk sharing are negative, it can still be valuable for the buyer.

We also study the interplay between risk sharing and conventional procurement strategies such as dual sourcing and noncompliance 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. Noncompliance 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 as a result of 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 efforts in addressing supply chain social responsibility when reputation costs are unknown may lead to interesting insights.

Endnotes

[1] We use the terminology *good* and *bad* efforts as 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 Volpe et al. 2013).

[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 governments and NGOs determines the likelihood of public disclosure. Although 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 approach accords with other papers in the literature (e.g., Chen and Lee 2017, Huang et al. 2017) that assume detection probability to be exogenous.

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

[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 important, this outcome is a *noisy*, or imperfect, signal of effort. That is, the buyer cannot deduce the supplier's effort decisions by observing the outcome (see, e.g., Bolton and Dewatripont 2004, p. 129; Mas-Colell et al. 1995, pp. 478–479).

[7] If $\delta \geq 1$, the supplier *benefits* from increasing operational risk, which is not realistic. By contrast, $\delta < 0$ 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 $\delta \to 1$). Although this is a socially optimal outcome, it is not necessarily preferable for the buyer because it has to balance *both* operational and reputation costs.

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

[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.

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

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

[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 because such a penalty can be subsumed in the supplier's operational loss X_S.

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

[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.

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