Managing Social Responsibility in Multi-tier Supply Chains

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April, 2015

Abstract

We consider a three level supply chain in which a Tier 2 supplier sells to a Tier 1 supplier, which in turn sells to a downstream (Tier 0) firm. The Tier 2 supplier potentially violates social and environmental standards, resulting in harm to the Tier 0 firm. Both the manufacturer and Tier 1 supplier can exert effort to improve the responsibility of the Tier 2 supplier. We show that the manufacturer’s optimal strategy is one of extremes, consisting of either direct control (only Tier 0 exerts effort) or delegation (Tier 1 is induced to exert effort by Tier 0). The former strategy is potentially less efficient than the latter, but avoids the moral hazard problem inherent in delegation. Under the manufacturer’s optimal strategy, we find that increased pressure from external stakeholders (consumers, NGOs, and governments) can decrease supply chain responsibility when the manufacturer shifts from a direct approach to a delegation approach. Lastly, we demonstrate that appropriately designed non-compliance penalties charged to the Tier 1 supplier or the manufacturer when a Tier 2 violation occurs can both coordinate the supply chain and eliminate perverse responses to external pressure, though such penalties may face challenging hurdles to implementation in practice.

Keywords: multi-tier supply chain management, social responsibility, moral hazard, delegation vs control

1 Introduction

On August 2, 2014, an explosion at a factory owned by the Kunshan Zhongrong Metal Products Co. Ltd. in Kunshan City, China, tragically killed 68 and injured 187 workers. According to a subsequent investigation, the explosion was caused by an exposed flame in a workshop filled with combustible metal dust. The primary business of Zhongrong is to provide aluminum wheel hubs for Dicastal, a key supplier for automotive manufacturer General Motors. For years, the workers of Zhongrong had complained about the metal dust build-up and poor ventilation in the factory; however, General Motors delegated the management of Zhongrong (in Tier 2) to its immediate supplier Dicastal (in Tier 1), and hence did not directly monitor or work to improve the safety of working conditions in Zhongrong’s factory (Shirouzu & Li 2014). In a different incident, in 2007 an unauthorized Tier 2

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supplier in Mattel’s supply chain used paint with an excessive content of lead in the production of children’s toys, prompting a series of recalls that ultimately cost Mattel $110 million and resulted in a severe drop in consumer confidence towards the company (Hoyt et al. 2008). In both cases, a supplier’s negligence, poor investment in worker safety, or unsafe production practices led to a disastrous outcome, and in both cases, the supplier engaging in such behavior was not the immediate supplier of a large multinational corporation like General Motors or Mattel, but rather a higher tier supplier with whom the downstream firm had no direct relationship. Such events, while tragic, are not uncommon. In a study examining 3,922 supplier relationships, Sedex (2013) determined that the risk of social and environmental responsibility violations increases in the higher tiers of the supply chain in both number and severity: the average number of responsibility violations is 18% higher in Tier 2 than in Tier 1, and 27% higher in Tier 3 than in Tier 2, and a larger fraction of incidents are classified as “major” or “critical” in higher tiers than in lower tiers.

Such violations can result in substantial financial costs to the buying firm, despite the fact that they occurred a significant “distance” away from the buyer (in supply chain terms). On one hand, the downstream firm may experience an immediate loss in demand if socially conscious consumers refuse to purchase products made in an unsustainable, unethical, or unsafe supply chain (Salfino 2014; Guo et al. 2014). Such losses impact demand for products sourced from the violating supplier, and hence have a magnitude proportional to the volume sourced from the offending supplier; we call such a cost the “direct loss” from a responsibility violation. On the other hand, responsibility violations can have broader ramifications beyond a reduction in the demand for the violating product. For example, the brand equity of the downstream firm can be significantly negatively impacted, causing demand losses for other products not sourced from the violating supplier or forcing the firm to expend significant resources to recover its reputation with its customer base (Lefevre et al. 2010; Doorey 2011). We call this cost, which is not necessarily proportional to the volume sourced from the offending supplier, an “indirect loss” resulting from violations in the supply chain.

The potential for responsibility violations at upper tier suppliers leads to a unique challenge for downstream buyers: broadly speaking, should the buyer directly manage the responsibility of its upper tier suppliers, or should it delegate the management of responsibility to its direct (Tier 1) partners? A majority of companies (93% according to Slowick 2013), including General Motors, Wal-Mart, and other large multi-nationals, choose to work only with their immediate suppliers, delegating control of

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1 Sedex is a not-for-profit membership online database which allows members to store, share, and report on information in areas like labor, standards health & safety, environment, and business ethics. It is the world’s largest collaborative platform for managing and sharing multi-tier supply chain data, with more than 30,800 members across 23 different industry sectors in 150 countries. Its members include P&G, Nestle, Unilever, etc.
responsibility efforts in higher tiers to their Tier 1 suppliers. Consequently, in a delegation strategy, the manufacturer (which we also refer to as the “Tier 0 firm”) engages in a relationship with the Tier 1 firm, and the Tier 1 firm monitors and manages the responsibility level of the Tier 2 supplier. Alternatively, some companies, including Hewlett-Packard and Migros, directly manage responsibility at their higher tier suppliers via initiatives such as supplier certification, performing factories audits, and providing a supplier compliance training program (Grimm et al. 2014). Thus, in a control strategy, while the Tier 0 firm sources a product from Tier 1, it also engages directly with Tier 2 to monitor and improve the level of social and environmental responsibility. Indeed, in theory firms need not follow either extreme strategy, and may instead employ a combination of both strategies, combining direct effort from Tier 0 with effort from a Tier 1 supplier to help manage the responsibility of a Tier 2 supplier.

The advantage of a control strategy is that the downstream firm can directly choose the effort exerted at a Tier 2 supplier to improve responsibility, avoiding the moral hazard problem inherent in a delegation strategy (Kayis et al. 2013). However, this could be costly, especially when Tier 1 suppliers have closer relationships with Tier 2 suppliers or more specific expertise or knowledge of the production process than Tier 0 firms. Moreover, even if direct control is cost efficient, the number of suppliers typically increases significantly in higher tiers of the supply chain, implying that a Tier 0 firm pursuing this strategy must manage the responsibility of a large and complex network of suppliers, a potentially complicated task. These observations lead us to pose the following research questions.

First, under what conditions should the downstream firm choose the control strategy, the delegation strategy, or some combination of the two? Are there any particular circumstances of the motivating examples discussed above that suggest one strategy or the other should be preferred? Second, what impact does pressure from external stakeholders (consumers, NGOs, and the government) have on the level of supply chain responsibility, both under the manufacturer’s optimal strategy and when the manufacturer is forced to use one particular strategy, e.g., due to supply chain complexity? And third, is there any mechanism by which a decentralized multi-tier supply chain may achieve the first best (centralized optimal) level of responsibility?

We answer these questions by analyzing a model of a stylized, three tier supply chain consisting of one Tier 0 buyer, or “the manufacturer,” one Tier 1 supplier, and one Tier 2 supplier. As our focus is to investigate how the manufacturer should manage responsibility risk at upper tier suppliers, we assume the Tier 1 supplier is perfectly responsible with zero risk of a violation; all responsibility violations come from the Tier 2 supplier. The risk at the Tier 2 supplier is characterized by a Bernoulli responsibility distribution: with some probability, the Tier 2 supplier is “compliant” (meaning it experiences no responsibility violations), and with complementary probability the supplier is “non-compliant,” i.e.,
experiences a responsibility violation that leads to both direct and indirect losses, as described above. To reduce the probability of a violation, both the Tier 1 supplier and the manufacturer can exert effort at the Tier 2 supplier. Their efforts are substitutable, representing activities such as certification or factory auditing. While effort is not directly contractable, the manufacturer is powerful and capable of designing its procurement contract with the Tier 1 supplier (e.g., establishing a wholesale price).

We find that either a pure control or a pure delegation strategy is always optimal for the manufacturer, and we discuss conditions under which each strategy is preferred. When the manufacturer is forced to operate using a single strategy—either always working through the Tier 1 supplier or always managing responsibility directly—greater external pressure always increases the supply chain’s responsibility level. However, when the manufacturer has the option to bypass the Tier 1 supplier and work directly with a Tier 2 supplier—in other words, when the manufacturer can optimally choose between a control strategy and a delegation strategy—increased external pressure may generate perverse incentives with the manufacturer, causing the manufacturer to change strategies and reduce the overall investment in responsibility. Specifically, increased pressure from consumers (in the form of larger boycotts from responsibility violations) or NGOs (in the form of more frequent audits and a higher probability of detecting violations) may actually decrease the level of responsibility in the supply chain, because this pressure causes the manufacturer to switch from the control strategy to the delegation strategy, which results in less effort in equilibrium. Greater responsibility effort is guaranteed only when pressure is imposed on the manufacturer in the form of greater indirect losses (e.g., penalties or fines from violations by governmental bodies). We also show that appropriately designed non-compliance penalties charged to either the Tier 1 supplier or the manufacturer whenever the Tier 2 supplier experiences a violation can coordinate the supply chain, achieving the centralized system optimal effort level, and eliminate counterintuitive responses to external pressure by aligning the firm’s actions with the intentions of external stakeholders. However, we discuss several practical issues surrounding the optimal penalty contracts which might make their implementation challenging.

The remainder of this paper is organized as follows. In §2, we briefly review the literature. §3 introduces the components of our model, §4 derives the manufacturer’s optimal strategy, and §5 analyzes the impact of external stakeholder on pressure on that strategy. §6 discusses how non-compliance penalties influence the results, and §7 extends our analysis to cover the case of complementary (rather than substitutable) effort activities by the Tier 1 supplier and manufacturer. §8 concludes the paper, and all proofs appear in Appendix A.
2 Literature Review

Supply chain social and environmental responsibility is a topic that has received increasing attention in recent years. The most relevant papers to our own in this stream are those that consider sourcing and supplier management strategies to improve social responsibility. Guo et al. (2014) consider how a buyer chooses between multiple suppliers, some of which are “responsible” and some of which are “non-responsible,” and analyze how external factors (e.g., consumer willingness-to-pay for responsibly sourced products) influences the buyer’s sourcing decision. In contrast to their model, which consists of fixed (exogenous) levels of responsibility, the Tier 2 supplier in our model has an endogenous level of responsibility that is determined by the effort levels of the Tier 0 and Tier 1 firms. While they also find that increased external pressure can lead to lower supply chain responsibility, in their model this occurs because of the buying firm’s desire to exploit consumer willingness-to-pay for responsibility, while consumers in our model have no such willingness-to-pay; rather, our results are driven by the manufacturer’s trade-offs between the direct control and delegation strategies. Cho et al. (2015) consider mechanisms to reduce a direct supplier’s incentive to use child labor in the production of the buyer’s product. In contrast to their model, in which the buying firm is forced to operate through the Tier 1 supplier and endure moral hazard, in our model the buyer has the option of bypassing the Tier 1 supplying and engaging directly with its Tier 2 supplier to improve social responsibility. In other related works, Kalkanci et al. (2012) compare social and environmental performance under voluntary and mandatory disclosure rules about product responsibility, Lewis et al. (2012) analyze supply agreements for sustainable quality supply under asymmetric information, Plambeck & Taylor (2014) show how to motivate a supplier’s compliance with environmental regulations when the supplier can evade a buyer’s audit, Chen & Lee (2014) compare different screening mechanisms and determine how they motivate the responsibility level of a firm’s immediate supplier, Chen et al. (2014) discuss how commitments between supply chain members can improve social responsibility, and Kim (2015) analyzes the optimal inspection frequency and non-compliance penalty for a firm that randomly experiences violations. Each of these papers consider asymmetric information regarding violations or responsibility levels, while in our model, all information is public; rather, the key tension in our model derives from the non-contractibility of the Tier 1 supplier’s effort to improve responsibility in Tier 2, combined with the capability of the Tier 0 buyer to directly manage responsibility in Tier 2 if it so desires.

A related topic is the management of risk in decentralized supply chains, specifically the risk deriving from supply chain disruptions in which an upstream supply chain member (e.g., a supplier) takes actions that impact the supply risk of the downstream supply chain member (e.g., a manufacturer). Many
different strategies for mitigating the risk of supply chain disruptions have been examined, including multi-sourcing, identifying sources of back-up supply, and carrying safety stocks (Anupindi & Akella 1993; Tomlin 2006; Babich et al. 2007). See Aydin et al. (2011) for a recent review of the literature in decentralized supply chain disruption risk management. In contrast to these studies, we consider supplier risks from social and environmental responsibility violations, which impacts the downstream firm via direct losses from reduced demand and indirect financial losses, rather than through a loss in supply; because of this, many of the above mitigation strategies for supply disruptions are not effective (e.g., carrying safety stocks is not an effective mitigation strategy for a disruption in the Tier 0 firm’s demand).

In addition, we consider a multi-tier supply chain, rather than the vast majority of works in the supply chain disruption literature which focus on two-tier (supplier-manufacturer) supply chains. However, there are a few existing works that explore risk management in multi-tier supplier chains. Ang et al. (2014), for instance, examine a supply chain with a manufacturer, Tier 1 suppliers, and risky (prone to disruption) Tier 2 suppliers under different endogenously determined supply chain structures. Bimpikis et al. (2014) also consider a manufacturer’s sourcing decision when Tier 1 suppliers endogenously choose amongst risky Tier 2 suppliers, with an emphasis on the impact of non-convexities in production function on formation of particular supply networks. While these papers assume that the manufacturer must always source through the Tier 1 supplier, we differ by focusing on the downstream buyer’s the choice of either working directly with a Tier 2 supplier or working through a Tier 1 supplier. Dong et al. (2014) discuss a quality control problem in a multi-level supply chain, comparing the optimal policy when the manufacturer does and does not directly source from a Tier 2 component supplier. In contrast to that work, we consider Tier 2 suppliers prone to responsibility risk, which, unlike quality risk, cannot be determined by inspecting the product at the Tier 1 stage, and unlike supply disruption risk, results in direct demand losses and indirect financial losses rather than supply losses.

Lastly, we note that in our model, a buying firm can delegate the management of responsibility risk in Tier 2 to a Tier 1 supplier. The effort exerted by that Tier 1 supplier to improve responsibility in Tier 2 is non-contractable, meaning the relationship between the buyer and Tier 1 supplier is that of a principal and an agent (Laffont & Martimort 2009). Hence, our work is also related to the extensive literature on principal-agent models in supply chains (e.g., Corbett & De Groote 2000, Yang et al. 2009) specifically those involving moral hazard (e.g., Krishnan et al. 2004, Babich & Tang 2012, Hwang et al. 2014), as the principal in our model (the buying firm) faces risk that is dependent on the actions of the agent (the Tier 1 supplier). In contrast to most of the literature involving principal-agent relationships
in supply chains, the multi-tier structure of our model implies that the principal can, at its discretion, completely bypass the Tier 1 agent and directly exert effort to manage the responsibility risk of a Tier 2 supplier. A number of recent works have explored this question in both economics and operations management. For example, Kayis et al. (2013) consider the choice between delegation and control when the decision in question is the procurement of a subcomponent, and Guo et al. (2010) analyze the performance of various outsourcing structures that are feasible in a three tier supply chain; we refer the reader to these works for a detailed summary of this literature. To the best of our knowledge, the trade-off between delegation and control has not been considered in the context of supplier social and environmental responsibility risk.

3 Model

We consider a three level serial supply chain with an end company (Tier 0), a Tier 1 supplier, and a Tier 2 supplier. For simplicity, we use “manufacturer” to refer to the end company, which can be either a conventional manufacturer or a consumer-facing retailer. The manufacturer faces one-time deterministic demand $d$ from its customers and sells products at unit price $p$. To provide the products, the manufacturer sources a critical component from the Tier 1 supplier at unit price $w$, and the Tier 1 supplier in turn sources critical components from the Tier 2 supplier at unit price $c$. We assume the selling price $p$ is fixed as might be the case, e.g., if the price is determined by market competition. In addition, the unit price $c$ from the Tier 2 supplier is exogenous, given that suppliers at this level produce commodity-type components with relatively stable prices. Naturally, we require $c \leq w \leq p$, so that it is profitable for each party to participate in selling the product. All other transaction or administrative costs are normalized to zero.

We assume the Tier 1 supplier is perfectly responsible while the Tier 2 supplier is subject to a risk of social and environmental responsibility violations. Examples of such violations, which we also call “non-compliance incidents,” include illegal and forced labor, factory fires or other accidents that occur due to negligence, or illegal hazardous waste emissions. Consistent with much of the risk management and responsibility literature (e.g., Tomlin 2006 and Guo et al. 2014), we model Tier 2 supplier responsibility risk with a Bernoulli distribution dictating whether the supplier is “non-compliant” with probability $\alpha(e)$ or “compliant” with probability $1 - \alpha(e)$, where $e$ is the effort exerted by the manufacturer and Tier 1 supplier to improve responsibility in Tier 2. The function $\alpha(e)$ thus determines the likelihood of a violation, while the magnitude of a violation is determined by both the direct and indirect loss parameters (described below). We assume that a responsibility violation occurs if (i) the supplier
is non-compliant, and (ii) the non-compliance is detected. The former factor is purely a function of
the efforts of the Tier 1 supplier and manufacturer, while the latter (detection of non-compliance)
may be a function of, for instance, the frequency of audits by the firm or NGOs, or the amount of
media pressure focused on the manufacturer’s supply chain. In particular, we adopt the functional
form \( \alpha(e) = \beta \lambda(e) \), where \( \beta \in [0,1] \) is the detection rate of responsibility violations and \( \lambda(e) \) is a
decreasing convex function that represents the probability of the Tier 2 supplier actually experiencing
a responsibility violation (determined by Tier 1 supplier and manufacturer effort). Where necessary,
we will also discuss the special case of the exponential risk function, \( \alpha(x) = \beta e^{-x} \).

To reduce the Tier 2 supplier’s probability of a responsibility violation \( \alpha(e) \), both the Tier 1 supplier
and the manufacturer can exert effort at the Tier 2 supplier. This may include more frequent audits,
a supplier training program to implement responsibility standards, technological support, or direct
financial subsidies for, e.g., safety improvements in the supplier’s facilities. We let \( e_i \) be the effort the
Tier \( i \) company exerts, and the cost of effort at firm \( i \) is \( k_i e_i \), where \( k_i > 0 \) is a constant. We consider
two cases regarding the form of total effort \( e \):

- **Substitutable Effort:** \( e = e_0 + e_1 \). This is suitable for efforts such as more frequent supplier
  monitoring and audits, e.g., to prevent child labor or excessive over-time, that are essentially
  interchangeable. In these situations, the total effort exerted in the supply chain is the sum of
  efforts from both the Tier 1 supplier and the manufacturer. This case is analyzed in the main
  portion of the paper.

- **Complementary Effort:** \( e = e_1 \cdot e_0 \). This is suitable for more complex responsibility improvement
  activities where the Tier 1 supplier and manufacturer each play an important, and independent,
  role in the success of the initiative. For instance, the manufacturer may possess the financial
  resources to purchase new, safer equipment for the Tier 2 supplier, while the Tier 1 supplier
  possesses the resources to train the Tier 2 supplier in the proper usage of the equipment and to
  continually monitor its effectiveness. In this case, successful investment requires effort from both
  companies, and greater effort from one firm makes the effort of the other firm more effective. We
  consider this case as an extension in §7.

As discussed in the introduction, a responsibility violation leads to both direct and indirect loss for
the manufacturer. To model the former effect, we assume that a percentage \( \gamma \) of the manufacturer’s
customers are “socially conscious” and abandon the manufacturer in the wake of a violation, leading

\(^2\)For example, certain companies, such as Apple or Wal-Mart, may draw greater scrutiny from the press and NGOs
due to their large global presence and dominance in the market; this greater scrutiny would result in a higher chance of
non-compliance being detected, and would be reflected in our model via larger \( \beta \) term.
Figure 1. Supply Chain Overview

to a demand loss $\gamma d$ (Guo et al. 2014). Hence, the direct effect is proportional to the manufacturer’s demand and will, in turn, affect the quantity sourced from the Tier 1 supplier. To model the latter effect, we assume that a violation leads to an indirect financial loss $a_0$ for the manufacturer (Plambeck & Taylor 2014). This includes any factors that are not proportional to the manufacturer’s demand and that do not impact the order the manufacturer places with the Tier 1 supplier. For instance, it may derive from recovery costs not directly associated with the non-compliant product, e.g., advertising costs to recover consumer confidence; alternatively, it may derive from other mechanisms such as a reduction in the manufacturer’s stock price (Lefevre et al. 2010). In addition, such costs may arise if the manufacturer must subsidize the supplier’s recovery efforts or compensate victims of the supplier’s negligence. For instance, after a fire in a Bangladeshi garment factory in 2012 which killed more than 100 workers, Li & Fung and other manufacturers whose products were made in Bangladeshi factories provided compensation for the victims of the fire and their families (Gustafsson 2013). Finally, the indirect loss term may also be impacted by additional fines or penalties applied by a regulator or governmental body. In addition to the manufacturer, the Tier 1 supplier may encounter a similar indirect financial loss $a_1$, deriving from similar sources. Figure 1 illustrates the supply chain structure and the impact of responsibility violations on the firms in our model.³

The manufacturer has full information regarding the supply chain, including the responsibility risk function $\alpha(e)$ and the effort cost parameter $k_i$ of the Tier 1 supplier. However, the Tier 1 supplier’s effort $e_1$ is not directly contractable, e.g., because effort is abstract and ill-defined, and verifying effort in a legally enforceable manner is challenging. In practice, a variety of incentives have been adopted by manufacturers to motivate the Tier 1 supplier’s effort. These strategies can be broadly categorized as “inducements” or “penalties.” For example, Starbucks pays 10% more for coffee beans grown with the

³We note that in practice, following a violation the Tier 2 supplier may lose some or all of its operating capacity, e.g., due to factory suspension or shut-down. For example, after the fire in the Bangladeshi apparel factory, not only was the affected factory clearly shut down for some time, many other factories in Bangladesh were also suspended while safety regulations were reviewed and updated (Gustafsson 2013). For simplicity and to focus on the impact of social and environmental responsibility risk on demand, we will not explicitly model capacity loss resulting from violations; however, our main results continue to hold after incorporating capacity losses driven by responsibility violations.
certification of fair trade, i.e., it induces responsible behavior with a high wholesale price. On the other hand, Wal-Mart and Sam’s Club have adopted a strict penalty policy, which terminates a supplier when its annual non-compliance violations exceeds a certain number. We consider both types of incentives in this paper. In the main analysis in §§4-5, we assume that the manufacturer offers a simple wholesale price only contract with parameter \( w \), i.e., penalties are not allowed. In §6, we consider the impact of non-compliance penalties by allowing the manufacturer to charge a fixed penalty \( \varphi \) to the Tier 1 supplier whenever a violation occurs in Tier 2. In both cases, the Tier 1 supplier will accept any contract as long as its expected profit from the contract is no lower than its reservation level, \( r \).

The manufacturer is assumed to be powerful (e.g., consistent with our motivating examples of firms such as General Motors and Mattel) and serves as a sequential leader both in setting the terms of the contract with Tier 1 and in determining its own responsibility efforts. The sequence of events is thus divided into three stages—a contracting stage, a production stage, and a selling stage—as follows. (1) At the beginning of the contracting stage, the manufacturer determines its effort level \( e_0 \) and chooses a contract to offer the Tier 1 supplier. After observing the contract and the manufacturer’s effort level, the Tier 1 supplier decides to accept or reject the offer. If it accepts the offer, it determines its effort \( e_1 \) to maximize its profit. (2) During the production stage, the efforts \( e_1 \) and \( e_0 \) take effect. Responsibility violations then randomly occur with probability \( \alpha(e) \), and the impact of a violation (demand loss \( \gamma \) and financial loss \( a_i \)) is realized. (3) After observing the non-compliance state, the manufacturer chooses its order quantity \( q \) from the Tier 1 supplier. Sales occur and the profit for each company is calculated.\(^4\) Figure 2 provides an illustration of the sequence of events.

The objective of each player is to maximize its individual expected profit. For a general contract consisting of both a wholesale price \( w \) and a non-compliance penalty \( \varphi \), let \( \Pi_i(w, \varphi, e_0, e_1) \) denote the

\(^4\)Note that in the selling stage, the manufacturer finalizes its order quantity after violations have been revealed; this is reasonable, because the Tier 2 supplier takes responsibility for non-compliance and in many cases would allow the manufacturer to adjust its order quantity \( q \) should non-compliance occur (see also Guo et al. 2014); moreover, if there is any capacity loss in Tier 2 associated with a responsibility violation (e.g., due to a factory shutdown in the wake of an accident or regulatory investigation), a natural opportunity exists for the manufacturer to adjust its order downward to match the reduced demand level.
expected profit function for the Tier \(i\) firm. Then the manufacturer solves the following optimization problem:

\[
\max_{p \geq w \geq c, e_0, e_1 \geq 0} \Pi_0 (w, \varphi, e_0, e_1^* (w, \varphi, e_0))
\]

\[
s.t. \quad e_1^* (w, \varphi, e_0) = \arg \max \{ e_1 \geq 0 : \Pi_1 (w, \varphi, e_0, e_1) \}
\]

\[
\Pi_1 (w, \varphi, e_0, e_1^* (w, \varphi, e_0)) \geq r
\]

We assume the problem is feasible, i.e., the model parameters are chosen so that there exists some \((w, \varphi, e_0)\) so that the Tier 1 supplier has profit larger than its reservation level \(r\). Because demand is deterministic, the manufacturer always finds it optimal to order its demand, leading to \(d\) under a compliance state and \((1 - \gamma) d\) under a non-compliance state. We may thus write the expected profit functions as

\[
\Pi_0 (w, \varphi, e_0, e_1) = (p - w) d - k_0 e_0 - \alpha (e) L_0 (w, \varphi)
\]

\[
\Pi_1 (w, \varphi, e_0, e_1) = (w - c) d - k_1 e_1 - \alpha (e) L_1 (w, \varphi)
\]

where \(L_1 (w, \varphi) = \gamma (w - c) d + a_1 + \varphi\) and \(L_0 (w, \varphi) = \gamma (p - w) d + a_0 - \varphi\). Here, \(L_i (w, \varphi)\) represents the Tier \(i\) company’s profit loss when a responsibility violation occurs in Tier 2. It includes the direct loss due to losing \(\gamma d\) demand, the indirect financial loss \(a_i\), and the internal contract penalty term \(\varphi\).

### 4 The Manufacturer’s Optimal Strategy

We begin by investigating the manufacturer’s optimal strategy under a wholesale price contract with no non-compliance penalty (\(\varphi = 0\)). Such contracts are widely observed in industry, due to their simplicity and convenience for negotiation and legal implementation (Kayis et al. 2013), especially when suppliers are averse to contractible liability for upper tier supply chain responsibility violations. We first establish a baseline for comparison by deriving the optimal strategy in a centralized supply chain, i.e., a supply chain in which a single decision maker determines the effort levels of both the Tier 1 supplier and the manufacturer in order to maximize total supply chain profit. The expected total supply chain profit can be written as

\[
\Pi (w, \varphi, e_0, e_1) = (p - c) d - k_0 e_0 - k_1 e_1 - \alpha (e) L
\]
Here, $L = \gamma (p - c) d + a_1 + a_0$ is the supply chain profit loss when a responsibility violation occurs at the Tier 2 supplier. Optimizing this profit function over manufacturer and Tier 1 effort yields the following result:

**Proposition 1.** In a centralized supply chain, it is optimal for the firm with lower effort cost to exert all effort, yielding

$$e^* = \begin{cases} 0 & \text{if } \frac{\min\{k_0, k_1\}}{L} \geq -\alpha'(0), \\ \left(\alpha'\right)^{-1}\left(-\frac{\min\{k_0, k_1\}}{L}\right) & \text{otherwise}. \end{cases}$$

Recall that substitutable effort activities, such as supplier factory audits or compliance monitoring, can be conducted by either Tier 0 or Tier 1 with no difference in impact on the risk of a violation. Therefore, the optimal strategy is intuitive: the system only exerts effort when the effort cost is low compared with the supply chain loss, and all effort should come from the firm with lower effort cost. Since Tier 1 suppliers usually have better information about and access to Tier 2 suppliers, a reasonable scenario in practice is that the Tier 1 supplier has lower unit effort cost than the manufacturer. In this case, the proposition shows that it is better to let the Tier 1 supplier handle all responsibility improvement efforts. However, it is also possible in practice that the manufacturer has greater knowledge about responsibility practices or more effective implementation tools, leading to $k_0 < k_1$; in these cases, the centralized optimal solution is for the manufacturer to exert all effort. To keep our focus on interesting scenarios, we assume it is optimal to exert non-zero effort under the centralized setting in the remainder of our paper. Specifically, we assume $k_i \leq -\alpha'(0) a_i$ under substitutable effort, which means the unit investment cost is lower than the indirect responsibility violation loss, which in turn ensures $e^* > 0$ is optimal in a centralized system.

Next, we consider a decentralized supply chain in which the manufacturer is forced to always follow one extreme strategy or the other, i.e., either delegation or control, but cannot optimally choose between the two. This might be the case if, for instance, Tier 1 suppliers do not have the means or resources to improve responsibility in Tier 2 (forcing the manufacturer to use a control strategy) or if the manufacturer is reluctant to become involved in the management of higher tier suppliers due to a lack of information about Tier 2 or the complexity of managing what in practice is a potentially large number of Tier 2 suppliers (forcing a delegation strategy). Define $e_0^c(w)$ ($e_1^d(w)$) to be the optimal effort level of the investing party in a pure control (pure delegation) strategy for some wholesale price $w$; from this point forward, we use the superscript $c$ to denote optimal values under a control strategy.
and d for optimal values in a delegation strategy. Then, we have:

\[
e^c_0(w) = \left(\alpha \right)^{-1} \left( -\frac{k_0}{L_0(w,0)} \right) \quad \text{and} \quad e^d_1(w) = \left(\alpha \right)^{-1} \left( -\frac{k_1}{L_1(w,0)} \right)
\]

(1)

In other words, \(e^c_0(w)\) is the optimal manufacturer effort when Tier 1 effort is fixed to zero (\(e_1 = 0\)), while \(e^d_1(w)\) is the optimal Tier 1 effort when manufacturer effort is fixed to zero (\(e_0 = 0\)). In both cases, the more costly the firm’s effort relative to its non-compliance loss, the lower effort that firm exerts. The manufacturer thus acts as a sequential leader in setting the wholesale price \(w\) to maximize its own profit, knowing that the induced effort level will be given by one of the two equations given in (1). We examine how these effort levels depend on the problem parameters after optimizing over the wholesale price \(w\) in §5.

Lastly, we move to a decentralized supply chain in which both the manufacturer and Tier 1 supplier independently determine their effort levels, and simultaneous positive effort from both parties is feasible. We begin by deriving the equilibrium effort levels given some wholesale price \(w\), then consider the subsequent equilibrium effort strategy under the optimal choice of \(w\) by the manufacturer. Let \((e^*_0(w), e^*_1(w))\) be the equilibrium effort levels induced by a particular wholesale price. Note that the manufacturer’s effort, \(e^*_0(w)\), is chosen first, and the Tier 1 supplier’s effort, \(e^*_1(w)\), is chosen second as a best response to the manufacturer’s effort and the wholesale price. Hence, the manufacturer induces some \(e^*_1(w)\) given its own choice of effort level. We thus refer to \((e^*_0(w), e^*_1(w))\) as the manufacturer’s optimal induced effort strategy given a wholesale price \(w\). Given these definitions, we have the following result:

\textbf{Proposition 2.} In a decentralized supply chain with a wholesale price contract, there exists a threshold price \(c \leq w_s \leq p\) such that the manufacturer’s optimal induced effort strategy is

\[
(e^*_0(w), e^*_1(w)) = \begin{cases} 
(e^c_0(w), 0) & , w \leq w_s \\
(0, e^d_1(w)) & , w > w_s
\end{cases}
\]

The proposition shows that the optimal induced effort strategy of the manufacturer for a fixed wholesale price is either a pure control strategy (for a low wholesale price) or a pure delegation strategy (for a high wholesale price), mimicking the effort levels derived in (1). No intermediate strategy, in which both firms exert positive effort, can be optimal. Thus, consistent with the centralized system, only one party exerts effort at the equilibrium; however, which party takes that responsibility depends on the wholesale price \(w\). The fact that such “pure” strategies are optimal occurs directly because of
the substitutable nature of responsibility improvement efforts. If the wholesale price is low, then the Tier 1 supplier’s incentive to exert effort is small, meaning the manufacturer must exert all effort by following a control strategy; conversely, if \( w_s \) is large, the Tier 1 supplier has strong incentive to exert effort, and hence the manufacturer will prefer to follow a delegation strategy.

Interestingly, while we might expect the manufacturer to follow a control strategy whenever it has a larger incentive to exert effort \( (a_0 > a_1) \) and its effort is more cost efficient than the Tier 1 supplier’s effort \( (k_0 < k_1) \), Proposition 2 implies that this is not necessarily true; in fact, the manufacturer’s strategy preference depends on the wholesale price, and even if \( k_0 < k_1 \) and \( a_0 > a_1 \), it is possible for some wholesale price that the manufacturer would prefer to follow a delegation strategy. Moreover, note that the Tier 1 supplier’s reservation profit level \( r \) is often interpreted as a proxy for the bargaining power of the supplier. When the Tier 1 supplier is very powerful (has a high reservation profit), this may lead to a high wholesale price (above \( w_s \)), which in turn would push the manufacturer to pursue a delegation strategy even if it is more efficient than the Tier 1 supplier in improving Tier 2 supplier responsibility.

Next, we analyze the manufacturer’s preference between these two extreme strategies under the optimal wholesale price \( w^* \). Let \( \Pi_i^s(w) \) denote the expected profit of firm \( i \) under strategy \( s \in \{c,d\} \), given the optimal effort described in the above proposition. When the manufacturer chooses to manage responsibility directly, its profit function is decreasing in \( w \) and thus it has no incentive to share more than the minimal reservation profit with the Tier 1 supplier. As a result, the optimal wholesale price is \( w^c \), where \( w^c \) is the minimum price satisfying \( \Pi_1^c(w) = r \). By contrast, if the manufacturer chooses to delegate responsibility management to the Tier 1 supplier, it needs to offer a wholesale price no lower than \( \hat{w} \), where \( \hat{w} \) is the minimal price satisfying \( \Pi_1^d(w) \geq r \). Thus, when the control strategy is optimal, the manufacturer extracts the maximal unit profit by setting \( w^* = w^c \) and exerts effort \( e_0^* = e_0^c(w^c) \).

On the other hand, when the delegation strategy is optimal, the manufacturer incentivizes the Tier 1 supplier to exert effort by offering a wholesale price \( w^* \geq \hat{w} \). Given these observations, we can identify under what circumstances each strategy is preferred:

**Proposition 3.** In a decentralized supply chain under the manufacturer’s optimal wholesale price contract, fixing all other parameters, there exist some thresholds (denoted by the over line \( \cdot \) symbol) such that the control strategy is optimal for the manufacturer if and only if:

(i) The cost of effort in Tier 0 is low \( (k_0 \leq \overline{k}_0) \);

(ii) The indirect loss in Tier 0 is high \( (a_0 \geq \overline{a}_0) \);

(iii) The cost of effort in Tier 1 is high \( (k_1 \geq \overline{k}_1) \);
(iv) The indirect loss in Tier 1 is low ($a_1 \leq \overline{a}_1$);
(v) The reservation profit of the Tier 1 supplier is low ($r \leq \tau$).

The first four cases are intuitive. In cases (i) and (ii), the manufacturer has strong incentive to exert high effort, either due to low cost ($k_0$) or high financial cost of a violation ($a_0$), and hence the manufacturer would prefer direct control to maximize the amount of effort exerted to improve responsibility. Conversely, in cases (iii) and (iv) the Tier 1 supplier does not exert sufficient effort under delegation, due to either high cost ($k_1$) or low financial costs of a violation ($a_1$). To understand case (v), recall that the manufacturer sets a very low wholesale price in a control strategy, leaving the Tier 1 supplier with exactly its reservation profit; when using delegation, however, the manufacturer must set a higher price to induce sufficient responsibility effort. Thus, when the reservation profit is very low, the temptation to use the control strategy is strongest, as this strategy allows the manufacturer to extract significant surplus. Thus, when the Tier 1 supplier is “weak,” implying a small $r$, the manufacturer prefers a control strategy. Put another way, case (v) shows that Tier 2 responsibility management should be left to the more powerful company, i.e., the control strategy is optimal for the manufacturer if the Tier 1 supplier is not powerful ($r$ is small) and the delegation strategy is optimal if the Tier 1 supplier is powerful ($r$ is large). Figure 3 illustrates these results by graphically depicting the manufacturer’s optimal strategy along with the corresponding optimal wholesale price as a function of several different parameter values. In the left panel, which depicts the optimal strategy as a function of $k_0$, $a_1$, or $r$, control is optimal for low parameter values and delegation is optimal for high parameter values. In the middle panel, delegation is optimal for low $k_1$ and control is optimal for high $k_1$. In the right panel, delegation is optimal for low $a_0$ while control is optimal for high $a_0$.

Note that Proposition 3 does not address the impact of direct losses ($\gamma$) or the detection probability ($\beta$) on the manufacturer’s optimal strategy. Intuitively, we might expect when the direct demand loss $\gamma$
increases, the manufacturer should choose the control strategy and more actively manage supply chain responsibility. However, this need not be the case, because unlike $k_i$ and $a_i$, the impact of demand loss $\gamma$ falls on both the manufacturer and the Tier 1 supplier, as demand loss equates to lost production volume for both firms in the supply chain. Hence, the Tier 1 supplier also feels greater incentive to exert effort as $\gamma$ increases, which may cause the manufacturer to shift from a control strategy to a delegation strategy once the supplier has sufficient incentive to improve responsibility. This can lead to the manufacturer’s optimal strategy being non-monotonic in $\gamma$, and consequently, the impact of direct losses on the manufacturer’s optimal strategy can be complex. In a similar manner, the detection probability ($\beta$) can potentially have a non-monotonic impact on the manufacturer’s optimal strategy.

Lastly, we consider how the decentralized supply chain’s total effort level compares to the centralized supply chain benchmark derived in Proposition 1. From the preceding results it is straightforward to see that:

**Corollary 1.** *Total effort in a decentralized supply chain is lower than total effort in a centralized supply chain.*

Thus, unsurprisingly, the wholesale price contract can never coordinate the supply chain. Much like the “double marginalization” effect commonly observed in decentralized supply chains (Cachon & Lariviere 2005), where dividing profit among the manufacturer and supplier results in too little inventory, in our model dividing the supply chain’s non-compliance loss $L$ among the manufacturer and Tier 1 supplier leads to responsibility effort under-investment, regardless of whether the manufacturer follows a direct control strategy or a delegation strategy when managing Tier 2 responsibility.

## 5 External Stakeholder Pressure

External stakeholders—in particular, socially conscious consumers, non-governmental organizations (NGOs), and policymakers in government—actively seek to encourage companies to exert more effort on improving supply chain responsibility. Socially conscious consumers, for example, influence $\gamma$, the demand loss that occurs in the wake of a responsibility violation, by boycotting products from affected companies. NGOs work with the media and third party auditing groups to increase the detection rate $\beta$ of violating suppliers. Policymakers in government may institute fines on both suppliers ($a_1$) and manufacturers ($a_0$) should a responsibility violation occur. In this section, we examine the impact of each of these external stakeholder actions on the level of responsibility in the supply chain.

Analyzing the effect of consumers and policymakers on responsibility effort can be accomplished via manipulation of the parameters listed above. In all cases, we assume that external stakeholders
move first and determine their efforts \((\gamma, \beta, a_0, \text{ and } a_1)\), after which the manufacturer optimizes its effort level and contract with the Tier 1 supplier as in the analysis in the previous section. Throughout this section, we assume an exponential risk function, \(\alpha(x) = \beta e^{-x}\), for concreteness, although many of the following results extend to a general risk function.

We begin by examining the impact of external stakeholder actions in a centralized supply chain. As the following proposition shows, in such a situation, as expected, external stakeholder pressure unequivocally increases the level of supply chain responsibility:

**Proposition 4.** In a centralized supply chain, total effort \(e^*\) is increasing in consumer pressure \((\gamma)\), NGO pressure \((\beta)\), and policymaker pressure \((a_0 \text{ and } a_1)\).

The reason for this result is that greater pressure along any of the listed dimensions increases the cost of a responsibility violation to the entire supply chain, which therefore increases the optimal level of effort for the centralized system. Most global supply chains, however, are unlikely to be vertically integrated. We thus move to the case of a decentralized multi-tier supply chain analyzed in §4. First, we consider the impact of external stakeholder pressure when the manufacturer is forced to use one strategy or the other:

**Proposition 5.** In a decentralized supply chain with a wholesale price contract,

(i) Fixing the manufacturer’s strategy to delegation, total effort \(e^*\) is increasing in consumer pressure \((\gamma)\), NGO pressure \((\beta)\), and policymaker pressure \((a_0 \text{ and } a_1)\).

(ii) Fixing the manufacturer’s strategy to control, total effort \(e^*\) is increasing in consumer pressure \((\gamma)\), NGO pressure \((\beta)\), and policymaker pressure on the manufacturer \((a_0)\) and decreasing in policymaker pressure on the Tier 1 supplier \((a_1)\).

This result shows that if the manufacturer is forced to always use one strategy, greater pressure from external stakeholders continues to unambiguously increase the level of supply chain responsibility in all cases except for one: when the manufacturer engages in direct control and increased pressure falls on the Tier 1 supplier in the form of a greater indirect loss \((a_1)\). The reason for this result is that the manufacturer must compensate the Tier 1 supplier with a greater wholesale price when \(a_1\) increases, in order for the supplier to achieve its reservation profit level \(r\); as a result of this higher wholesale price, the manufacturer earns less margin and thus feels less incentive to exert direct effort to improve responsibility in Tier 2. Nevertheless, in all other cases, external pressure leads to outcomes consistent with the centralized supply chain case. In many practical settings the manufacturer may be forced into one strategy or the other; most models of two-tier supply chains make precisely this assumption, and
the complexity and sheer number of Tier 2 (and higher) suppliers may necessitate the use of delegation. In such cases, most sources of external pressure from continue to improve responsibility effort in the supply chain.

In fact, a key feature of a multi-tier structure is that the manufacturer possesses the option of choosing its strategy optimally: delegation or control can be used in accordance with the optimality conditions discussed in Proposition 3. As the following proposition shows, when this is the case, external stakeholders may have quite a different impact on the responsibility effort in the supply chain:

**Proposition 6.** In a decentralized supply chain with a wholesale price contract, under the manufacturer’s optimal strategy, total effort $e^*$ is increasing in policymaker pressure on the manufacturer ($a_0$), but may be increasing or decreasing in consumer pressure ($\gamma$), NGO pressure ($\beta$), and policymaker pressure on the Tier 1 supplier ($a_1$).

Proposition 6 shows that when increased policymaker pressure falls only on the manufacturer, i.e., $a_0$ is larger, the equilibrium system effort increases; in this case, the manufacturer alleviates its loss either by exerting more effort itself or offering a higher price to the Tier 1 supplier to induce greater effort. However, when pressure falls on the entire supply chain (via a higher detection rate $\beta$ or greater consumer pressure $\gamma$), or when pressure falls only on the Tier 1 supplier (a higher Tier 1 supplier penalty $a_1$), equilibrium supply chain effort may be decreasing in external stakeholder pressure.

Figure 4 illustrates two examples of this effect.\(^5\) Focusing on the left panel, observe that for low $\beta$, the manufacturer engages in the direct control strategy and exerts all responsibility effort on its

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\(^5\)In the figure, the risk function is $\alpha(x) = \beta e^{-x}$ and parameter values are $c = 0.5$, $p = 3$, $d = 1$, $a_0 = 2$, $k_0 = 0.5$, $\gamma = 0.5$ and $r = 0$. In the left panel, $a_1 = 1$, while in the right panel, $\beta = 1$. 

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Table 1. The impact of external stakeholder pressure on equilibrium responsibility effort under an exponential risk function $\alpha(x) = \beta e^{-x}$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Centralized Supply Chain</th>
<th>Decentralized - Delegation</th>
<th>Decentralized - Control</th>
<th>Decentralized - Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\uparrow a_0$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>$\uparrow a_1$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\downarrow$</td>
<td>$\uparrow$</td>
</tr>
<tr>
<td>$\uparrow \beta$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\downarrow$</td>
</tr>
<tr>
<td>$\uparrow \gamma$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\uparrow$</td>
<td>$\downarrow$</td>
</tr>
</tbody>
</table>

own, in the process taking all supply chain profit above the supplier’s reservation level. However, as pressure from the NGO increases, the Tier 1 supplier feels greater loss from a violation, leading it to exert greater effort under a delegation strategy; hence, once $\beta$ is sufficiently large (greater than approximately 50%), the manufacturer shifts its strategy, delegating responsibility management to the Tier 1 supplier. At this point, the total system effort drops significantly, because the Tier 1 supplier has both a smaller share of the supply chain’s profit and a smaller indirect loss than the manufacturer. While this shift to delegation increases the risk of a violation for the manufacturer compared to the control strategy, it means the manufacturer does not need to exert any effort, and overall results in greater profit for the manufacturer. As $\beta$ continues to increase and both the supplier and manufacturer feel a greater expected loss from a violation, the supplier exerts greater effort, eventually raising total system effort above the level exerted by the manufacturer under the control strategy. In addition, changes in $\gamma$ can result in a similar impact on total system effort as changes in $\beta$.

On the other hand, when policymakers impose a higher violation penalty $a_1$ for the Tier 1 supplier, total responsibility effort does not necessarily behave monotonically, as the right panel in Figure 4 illustrates. When $a_1$ is small, the manufacturer uses the direct control strategy; as $a_1$ increases, the Tier 1 supplier has more incentive to exert effort on its own, and hence the manufacturer switches to a delegation strategy, which reduces total supply chain effort. Note that when $a_1$ is small and the manufacturer chooses a control strategy, greater $a_1$ may lower the supply chain’s total effort level even if there is no shift in the optimal strategy, consistent with Proposition 5 part (ii).

These results are summarized in Table 1. As the table demonstrates, when the supply chain is decentralized, external pressure need not improve supply chain responsibility. This effect arises because of the multi-tier structure of our model, and the manufacturer’s option to choose either a control or delegation strategy; whenever the manufacturer is forced to use one strategy, external pressure is far less likely to have detrimental impact on supply chain responsibility. We stress that these counterintuitive results need not always occur; they are only present when the manufacturer’s optimal strategy shifts from control to delegation in response to an increase in $\gamma$, $\beta$, or $a_1$. Such a shift may or may not occur.
over the feasible range of these parameter values. Nevertheless, these examples illustrate the perverse impact that greater external pressure can have when a firm can optimally choose between delegation and control when managing supply chain responsibility.

6 Penalty Contracts

Penalty contracts are often effective for inducing supply chain coordination in moral hazard settings prone to some type of risk (e.g., Ang et al. 2014). Since our analysis thus far shows that wholesale price contracts always result in under-investment in responsibility effort, one natural question to ask is: can an appropriately designed penalty contract coordinate a decentralized supply chain, and if so, how does this impact the effects of external stakeholders on supply chain responsibility?

Consider first the case when $k_0 \geq k_1$, i.e., the Tier 1 supplier is more cost efficient than the manufacturer. Recall that in this case, under the centralized supply chain it is optimal for all effort to come from the Tier 1 supplier, i.e., $e_1^* = \left(\alpha^1\right)^{-1} \left(-\frac{k_1}{\theta}\right)$. In order to coordinate the supply chain, the manufacturer should be able to induce this exact effort level from the Tier 1 supplier, while exerting no effort on its own, i.e., $e_0^* = 0$. Penalties levied on the Tier 1 supplier potentially give that supplier larger incentive to exert effort to reduce responsibility risk; however, a penalty also reduces the Tier 1 supplier’s profit (all else being equal), and hence the supplier’s willingness to participate in the contract. To compensate for this, the manufacturer needs to offer a higher wholesale price $w$. Thus, the tradeoff between the wholesale price $w$ and penalty $\varphi$ results in a more complicated contract optimization problem for the manufacturer. To ensure that the manufacturer wishes to participate in the decentralized supply chain, we must assume its profit under the centralized setting is non-negative, i.e.,

$$\theta^* = \frac{\Pi^* - r}{(p - c)d} \geq 0.$$

Here, $\theta^*$ represents the manufacturer’s maximum profit percentage; the higher $\theta^*$ is, the more profit can be allocated to the manufacturer (after accounting for the Tier 1 supplier’s reservation profit). Given this definition, the following proposition describes the coordinating penalty contract:

**Proposition 7.** When $k_0 \geq k_1$, the decentralized supply chain can be coordinated by a penalty contract with the manufacturer attaining its maximum profit $\Pi^* - r$. The coordinating contract has wholesale price $w^* = (1 - \theta^*)(p - c) + c$ and penalty $\varphi^* = \gamma (p - w^*)d + a_0$.

Note that this coordinating contract possesses a simple structure, assigning the manufacturer exactly $\theta^*$ percent of the total profit margin $(p - c)$, which greatly facilitates contract implementation.
Moreover, given that the optimal penalty term $\varphi^*$ transfers all the responsibility risk to the Tier 1 supplier, the manufacturer has the same profit under both a compliant and non-compliant state, i.e., the manufacturer’s profit is no longer stochastic under the optimal penalty contract.

Table 2 illustrates how each of the key problem parameters influences the manufacturer’s optimal wholesale price and non-compliance penalty. Interestingly, the optimal wholesale price and penalty do not necessarily move together monotonically, as is superficially suggested by the expressions in Proposition 7. On one hand, the penalty itself must reflect the manufacturer’s lost profit during a violation, which in turn is smaller under a higher wholesale price, implying a higher wholesale price should be accompanied by a smaller penalty. Hence, if either $k_1$ or $a_1$ increase and the manufacturer’s optimal profit share ($\theta^*$) decreases, leading to a higher wholesale price, the manufacturer will adjust by offering a smaller penalty. On the other hand, if either $a_0$ or $\gamma$ increase, the manufacturer’s loss during a violation increases, necessitating a larger penalty; to compensate for this larger penalty, the manufacturer must offer larger wholesale price to maintain the supplier’s reservation profit $r$. Hence, the wholesale price and penalty may exhibit a complex relationship.

Conversely, when $k_0 < k_1$, the centralized optimal action is for the manufacturer to exert all effort. In this case, any coordinating contract must give the manufacturer proper incentive to induce the system-wide optimal effort level; since the manufacturer bears all of the cost of effort, this can only be achieved if the manufacturer also feels all of the loss associated with responsibility violations. Hence, the optimal coordinating contract will include a penalty on the manufacturer that transfers all of the Tier 1 supplier’s loss during a violation to the manufacturer. Using the same contract variables as in the above analysis, this equates to a negative $\varphi$ parameter, as the following proposition shows:

**Proposition 8.** When $k_0 < k_1$, the decentralized supply chain can be coordinated by a penalty contract with the manufacturer attaining its maximum profit $\Pi^* = r - c$. The coordinating contract has wholesale price $w^* = \frac{r}{d} + c$ and penalty $\varphi^* = -\gamma r - a_1$.

This shows that in order to achieve the first best outcome in a decentralized supply chain when the manufacturer is more efficient at responsibility effort, the manufacturer must tell the Tier 1 supplier...
that (i) it will take full responsibility for engaging the Tier 2 supplier in responsibility improvement, and (ii) the manufacturer will compensate the Tier 1 supplier for its losses in the event of a violation in Tier 2. While intuitive—such a transfer of losses is necessary to place the full level of risk in the hands of the party exerting the effort—such contracts seem far less common in practice than either wholesale price only contracts or “standard” penalty contracts in which the Tier 1 supplier is penalized for violations (perhaps this rarity is due in part to the fact that in most realistic scenarios, the Tier 1 supplier is more efficient at improving responsibility than the manufacturer). Nevertheless, the result shows that the manufacturer can achieve coordination by paying the Tier 1 supplier a low wholesale price and a subsidy whenever a violation occurs, leaving the supplier with exactly its reservation profit \( r \) in both the non-compliant and compliant states.

In either of these cases, it is immediately clear that Proposition 4—which details the impact of external pressure on the optimal effort level in a centralized supply chain—holds under the optimal coordinating contract. That is, when the supply chain is appropriately coordinated using penalties, greater external stakeholder pressure always leads to an increase in responsibility effort. This happens because the optimal penalty transfers the entire cost of a responsibility violation to the party exerting effort, and hence any increase in cost due to external stakeholder pressure leads to an increase in effort to improve responsibility. Put another way, under the optimal coordinating penalty contract, the more efficient firm always engages in responsibility improvement efforts, hence changes in external stakeholder pressure do not change the manufacturer’s optimal strategy from control to delegation. Thus, the counterintuitive response to external stakeholder pressure, in which a manufacturer switches strategies and reduces investment in responsibility, is eliminated if the supply chain properly employs non-compliance penalties.

The use of penalties to transfer supply chain loss from one party to another in order to induce optimal investment is well known in the literature.\footnote{For instance, in contract law under expectation damages, the breaching party is ordered to reimburse the injured party for its losses, which exactly equals \( \varphi^* \) in our case. In the operations literature, Plambeck & Taylor (2007) analyze the impact of such damages in repeated relationships and contract design.} However, despite the theoretical effectiveness of such contracts, there are key obstacles to their practical implementation (see, e.g., Chen & Lee (2014) and Plambeck & Taylor 2014). In our setting, several specific challenges arise. First, in the \( k_0 \geq k_1 \) case, the Tier 1 supplier may be unwilling to accept a penalty contract. In most practical cases, the dollar amount of the brand reputation damage for the manufacturer is much larger than that of the supplier, resulting in \( a_0 \gg a_1 \). This leads to a high wholesale price \( w^* \), but also a very high penalty \( \varphi^* \). Thus, the Tier 1 supplier may be faced with an enormous penalty when a responsibility violation occurs, something that may preclude accepting the contract if the Tier 1 supplier is risk
averse or very powerful and capable of dictating whether penalties are employed. Even if the Tier 1 supplier is willing to accept the contract, enforcing the penalty may be difficult, given that many Tier 1 suppliers are small companies from emerging economies whose pockets may not be deep enough to cover such significant penalties. Conversely, if the manufacturer is risk averse, it may also be unwilling to pursue the optimal contract in the $k_0 < k_1$ case, as this exposes the manufacturer to a potentially large variance in profit. Hence, risk preferences and capital constraints may make implementation of the optimal coordinating contracts challenging. Finally, the Tier 1 supplier may not have incentive to provide accurate information to the manufacturer, such as its effort cost $k_1$. Note that a higher effort cost leads to a higher wholesale price and lower penalty for the Tier 1 supplier, both favorable outcomes; hence, the Tier 1 supplier may have incentive to lie about or misrepresent this information in an attempt to generate greater profit. Consequently, while penalty contracts are theoretically effective at eliminating the coordination problem in a decentralized supply chain, these barriers may make their implementation costly, or even infeasible, in practical settings.

7 Complementary Effort

In our main model, we assumed that manufacturer and Tier 1 supplier efforts were completely substitutable. This resulted in an optimal allocation of effort that was extreme: in both the centralized and decentralized supply chains, the optimal strategy was either one of pure delegation (Tier 1 exerts all effort) or pure control (the manufacturer exerts all effort). In this section we consider the how our results change under complementary efforts, such as the manufacturer providing equipment and the Tier 1 supplier working with and supervising the Tier 2 supplier in the use of that equipment. Specifically, in contrast to the additive aggregate effort function used in the preceding analysis ($e = e_0 + e_1$), under complementary effort we assume that total effort is the product of the manufacturer’s and supplier’s effort, i.e., $e = e_0 e_1$. For ease of analysis, throughout our discussion of complementary effort we consider the exponential risk function $\alpha(x) = \beta e^{-x}$, although most results are readily extended to a general risk function.

The details of our analysis for this case and the derivation of the manufacturer’s optimal sourcing strategy are contained in Appendix A. To summarize, it is clearly no longer optimal for the supply chain to follow the pure delegation or pure control strategies, as under either extreme strategy—in which all effort is exerted by a single firm—aggregate effort is zero. Thus, in both the centralized and decentralized systems, the optimal effort is either zero for both firms or positive for both firms. This fact leads to the following proposition, which illustrates the impact of complementary effort on our key
result: the effect of external stakeholder pressure on supply chain responsibility.

**Proposition 9.** Under complementary effort, in either a centralized supply chain or a decentralized supply chain with a wholesale price contract, the system total effort $e^*$ is increasing in consumer pressure ($\gamma$), NGO pressure ($\beta$), and policymaker pressure ($a_0$ and $a_1$).

Thus, in contrast to the case of substitutable activities (Propositions 4–6), when responsibility improvement efforts are complementary, external stakeholder pressure has an unequivocal impact on supply chain responsibility: greater pressure from any source always leads to more responsibility effort. This holds regardless of whether the supply chain is centralized, decentralized and coordinated, or decentralized and uncoordinated (i.e., decentralized and operating with wholesale price contracts with no non-compliance penalties). This result arises directly because of the complementary nature of effort and the fact that in equilibrium both firms exert positive (or zero) effort simultaneously. Greater pressure from any external stakeholder leads to at least one member of the supply chain raising its effort level, e.g., greater policymaker pressure on the Tier 1 supplier leads to that supplier raising its effort level. When this happens, the other supply chain member will respond by adjusting its own effort level such that the aggregate effort level ($e = e_1e_2$) is raised to a level at least as high as was optimal before the increased pressure, as that firm can accomplish this at a lower cost (i.e., with less of its own effort) than it previously could. Hence, the aggregate effort level will increase in response to greater external pressure.

Thus, when the supply chain responsibility efforts are complementary in nature, more pressure from external parties is always beneficial. For instance, in industries with a significant environmental impact (e.g., chemicals and pharmaceuticals, tanning of textiles, and mining and refining of metals), the chief responsibility concerns frequently center around toxic waste disposal, water pollution, hazardous greenhouse gas emissions, etc. In these cases, improving supply chain responsibility may involve both investing in cleaner equipment and working with the Tier 2 supplier to train its employees in the usage of clean technologies, implying joint efforts are required. Under these circumstances, our results show that supply chain responsibility can be improved by all forms of external stakeholder pressure.

By contrast, in many labor intensive industries, human rights violations are key sources of responsibility violations, e.g., forced or child labor or unsafe working conditions. The typical responsibility improvement activities in such cases, such as frequent supplier audits or financial subsidies to improve working conditions, are interchangeable and can be conducted by either the Tier 1 supplier or the manufacturer, implying substitutable efforts. Our results from the preceding sections shows that in such cases, when external stakeholders exert pressure with the intent of improving supply chain re-
sponsibility, their actions may backfire. Thus, we conclude that the nature of efforts—substitutable or complementary—plays a key role in generating the undesirable reaction of the manufacturer to increased external stakeholder pressure.

8 Conclusion

In supply chains with multiple tiers, downstream buyers are faced with a deceptively simple question: should higher tier suppliers be managed directly, or should their management be delegated to intermediate (e.g., Tier 1) suppliers? Delegation is less complex and, very often, more efficient from the point of view of total supply chain cost; conversely, direct control subverts the moral hazard problem inherent in delegation. In this paper, we have explored the consequences of this trade-off in the context of the management of social responsibility risk stemming from a Tier 2 supplier.

Our results have several implications. First, they provide guidance to downstream firms on how to optimally choose an upper-tier supplier management strategy in the presence of responsibility risk. Under substitutable effort to reduce responsibility risk, the downstream manufacturer should pursue an all-or-nothing strategy: either delegate all management of Tier 2 to the Tier 1 supplier, or assume all management duties directly. Returning to the motivating examples discussed in the introduction, consider the incidents in the supply chains of General Motors and Mattel. In the case of GM, which experienced an explosion at the factory of a Tier 2 supplier, the effort required to avoid this disaster would include closer work with and monitoring of the Tier 2 supplier, which is likely less costly for Dicastal than GM, given the physical proximity of and familiarity between the companies; this suggests \( k_1 \) is much smaller than \( k_0 \). Moreover, the ultimate indirect loss caused by the explosion in Zhongrong’s factory to GM was likely small (\( a_0 \) is small), and Dicastal is a rather powerful manufacturer (it is the world’s largest wheel manufacturer, implying \( r \) is large). These conditions combine to imply that delegation is likely optimal for GM. However, in the case of Mattel, which discovered lead paint in its products, the situation is quite different. The direct cost to Mattel stemming from the incident was substantial (\( a_0 \) is large), while the type of effort required to avoid the incident, i.e., testing products for hazardous materials, likely costs both Mattel and any of its Tier 1 suppliers a similar amount (i.e., \( k_0 \approx k_1 \)). In addition, Mattel’s direct supplier (Lee Der Industrial Co.) is far less powerful than Dicastal, which suggests \( r \) is small. These factors suggest that direct control of upper tier responsibility is likely optimal in the case of Mattel.

Second, we also show that, for the manufacturer, a penalty contract can coordinate the supply chain while simultaneously allowing the firm to extract all profit above the Tier 1 supplier’s reservation
level; however, the optimal coordinating penalty contract might involve the manufacturer itself being penalized for responsibility violations. Importantly, penalty contracts allow delegation to achieve the first best outcome when the Tier 1 supplier is more efficient at exerting effort than the manufacturer. Thus, we add to the literature on penalty contracts (Ang et al. 2014; Hwang et al. 2014; Plambeck & Taylor 2014) by illustrating that such contracts are potentially extremely useful in the management of responsibility risk, given that global supply networks are increasingly long and complex, making direct control of upper tier responsibility management impractical for many manufacturers. However, as we discuss, there are a number of practical obstacles to the implementation of such contracts that may make them infeasible in many real world scenarios.

Third, as much of our analysis centers around the impact of external stakeholder pressure from consumers, NGOs, and policymakers, our results add to the growing supply chain literature that illustrates how these parties should (and should not) exert pressure to attempt to influence the responsibility level of a supply chain (Kalkanci et al. 2012; Plambeck & Taylor 2014; Guo et al. 2014; Cho et al. 2015). Intuitively, in a centralized supply chain (or one coordinated via penalty contracts), increased pressure from any of these stakeholders always results in greater supply chain responsibility. In a decentralized supply chain under substitutable efforts, however, when the manufacturer optimally chooses between the delegation and control strategies, greater pressure from external stakeholders can lead to a reduction in supply chain responsibility. When effort is complementary, greater external pressure always leads to greater responsibility. This suggests that external stakeholders should pay close to attention to the relationships in a supply chain as well as the type of effort (complementary or substitutable) required to reduce the chance of violations. Awareness of this issue can maximize the effectiveness of external stakeholder pressure in improving supply chain responsibility.

Lastly, our results show how the multi-tier structure we have analyzed can lead to new insights in principal-agent settings (Yang et al. 2009; Babich & Tang 2012; Kayis et al. 2013). Because the effort is exerted in the facility of a third party (i.e., the Tier 2 supplier), while the manufacturer can act as a principal in inducing the agent (i.e., the Tier 1 supplier) to exert effort, the manufacturer can also bypass the Tier 1 supplier and exert responsibility improvement effort directly. The manufacturer’s optimal choice between these two approaches leads to new qualitative effects (such as external pressure reducing supply chain responsibility) that are not present in a supply chain with only two firms or when the manufacturer is forced into a single strategy. Hence, in addition to reinforcing the notion that either delegation or control may be be optimal (Kayis et al. 2013), our results illustrate that switching between strategies may lead to interesting and, potentially, problematic effects.

As supply chains continue to swell in both length and breadth, the management of multi-tier
supply chains is an area that will undoubtedly only grow in importance in the coming years. Our model thus serves as both a first step in analyzing responsibility management in this setting, as well as an illustration of some of the important implications of managing suppliers in extended supply chains.

References


A Proofs

**Proof of Proposition 1.** If $k_0 \geq k_1$, for any effort set $(e_0, e_1)$, a new effort set $(0, e_0 + e_1)$ would result in a non-increasing cost $\Pi(w, \varphi, e_0, e_1)$. Therefore $e^*_0 = 0$. Since $\alpha(x)$ is a decreasing and convex
function, \( \Pi(w, \varphi, e_0, e_1) \) is concave with the optimal

\[
e_1^* = \begin{cases} 
0 & \text{if } -\alpha'(0) \leq \frac{k_1}{L_1(w)}, \\
\left(\alpha'\right)^{-1}\left(-\frac{k_1}{L_1(w)}\right) & \text{otherwise}.
\end{cases}
\]

The analysis for \( k_0 < k_1 \) is similar, which leads to the result in the proposition. \( \square \)

**Proof of Proposition 2.** We first analyze the Tier 1 supplier’s optimal effort strategy given the manufacturer’s wholesale price \( w \) and effort level \( e_0 \). The profit function for the Tier 1 supplier is

\[
\Pi_1(w, 0, e_0, e_1) = (w - c) d - k_1 e_1 - \alpha(e_0 + e_1) L_1(w).
\]

Since \( \Pi_1(w, 0, e_0, e_1) \) is concave with respect to \( e_1 \), some \( e_1^*(0, w) \) is optimal only if it satisfies the first order condition, \( \alpha'(e_0 + e_1^*(0, w)) = -\frac{k_1}{L_1(w)} \). This implies \( e_1^*(0, w) = \max \left\{ e_1^d(w) - e_0, 0 \right\} \). Moving next to the manufacturer’s effort level, note that either the manufacturer will exert some effort \( e_0 < e_1^d(w) \) or some effort \( e_0 > e_1^d(w) \). In the former case, the manufacturer will achieve the same aggregate effort level \( e_1^d(w) \) for any \( e_0 \), hence the manufacturer will choose \( e_0 = 0 \) to minimize cost. In the latter case, the manufacturer will induce the Tier 1 supplier to exert zero effort, leading to an optimal (manufacturer and aggregate) effort level equal to \( e_0^*(w) \). Define \( T = \left( \alpha(e_1^d(w)) - \alpha(e_0^*(w)) \right) L_0(w) - k_0 e_0^*(w) \) to be the difference in profit under these two extreme strategies. \( e_0^* = 0 \) if \( T < 0 \) and \( e_0^* = e_0^*(w) \) if \( T \geq 0 \). Let \( w \) satisfy \( \frac{k_0}{L_0(w)} = \frac{k_1}{L_1(w)} \). When \( w > \bar{w} \), \( \frac{k_0}{L_0(w)} > \frac{k_1}{L_1(w)} \) and \( T < 0 \). When \( w \leq \bar{w}, \frac{k_0}{L_0(w)} > \frac{k_1}{L_1(w)} \) and \( \alpha(e_0^*(w)) < \alpha(e_1^d(w)) \). Taking the derivative of \( T \) over \( w \), we have \( \frac{\partial T}{\partial w} < 0 \) when \( w \leq \bar{w} \). Therefore, there exists a threshold wholesale price \( w_s \) so that when \( w \leq w_s, T \geq 0 \), yielding the result in the proposition. Lastly, to test the sensitivity of \( w_s \) to the model parameters, consider the monotonicity of \( T \). Since \( T \) is decreasing in \( a_1 \) and \( w \) when \( w \leq \bar{w} \), \( w_s \) is decreasing in \( a_1 \). Similarly, it follows that \( w_s \) is increasing in \( a_0 \) and \( k_1 \), decreasing in \( k_0 \). \( \square \)

**Proof of Proposition 3.** The manufacturer’s optimal profit under the control strategy is

\[
\max_{c \leq w \leq w_s} \left( p - w \right) d - k_0 e_0^*(w) - \alpha(e_0^*(w)) L_0(w)
\]

\[s.t. \ (w - c) d - \alpha(e_0^*(w)) L_1(w) \geq r\]

Manufacturer profit is decreasing in \( w \). Thus the manufacturer’s optimal control strategy price is the minimal price satisfying the Tier 1 supplier’s participation constraint, which is defined to be \( w^e \). The
manufacturer’s optimal profit under the delegation strategy is

\[
\max_{w_1 \leq w \leq p} (p - w) d - \alpha \left( e_1^d (w) \right) L_0 (w)
\]

\[
s.t. \ (w - c) d - k_1 e_1^d (w) - \alpha \left( e_1^d (w) \right) L_1 (w) \geq r
\]

The Tier 1 supplier’s profit is increasing in the wholesale price, thus there exists a threshold \( \hat{w} \) such that the participation constraint is satisfied for all \([\hat{w}, p]\). Next, we consider the manufacturer’s strategy preference. For \( k_1 \), the optimal profit under control strategy is independent of \( k_1 \). However, Tier 1 supplier profit is decreasing in \( k_1 \), therefore the feasible set \([\hat{w}, p]\) is shrinking (i.e., \( \hat{w} \) is growing). At the same time, \( w \) increases in \( k_1 \) (per the proof of Proposition 2) and the manufacturer profit is decreasing in \( k_1 \). Thus the optimal profit under a delegation strategy is decreasing in \( k_1 \), yielding part (iii) of the proposition. The result for \( k_0 \) follows similarly, yielding part (i).

To see the impact of \( r \) on the manufacturer’s strategy, consider the price that maximizes the manufacturer’s profit under the delegation strategy, which we denote as \( w_1 \). When there are multiple maximizers, set \( w_1 \) be the largest one. When \( r \leq \Pi_1^d (w_1) \), the manufacturer’s optimal delegation strategy price is \( w^d (r) = w_1 \) and the manufacturer’s delegation strategy profit is independent of \( r \). At the same time, the manufacturer’s profit under control strategy decreases with \( r \) (which leads to a larger wholesale price \( w^c \)), leading to part (v) when \( r \leq \Pi_1^d (w_1) \). When \( r > \Pi_1^d (w_1) \), if \( \Pi_0^d (w) \) is decreasing on \([w_1, p]\), the manufacturer’s optimal delegation strategy price \( w^d (r) = \hat{w} (r) \) is increasing in \( r \) and the participation constraint is binding. The total supply chain profit under the delegation strategy is increasing due to higher system effort \( e_1^d (w^d (r)) \) while the total supply chain profit under control strategy is decreasing due to lower system effort \( e_0^c (w^c (r)) \). At the same time, the Tier 1 supplier receives the same reservation profit \( r \) under the control and delegation strategies. Thus, the difference of the manufacturer’s profit under delegation strategy and control strategy is also increasing. If \( \Pi_0^d (w) \) is not monotone on \([w_1, p]\), i.e., there are other maxima of \( \Pi_0^d (w) \) on the range \((w_1, p)\), find the maximum with the highest manufacturer profit and denote it as \( w_2 \). Define \( b \) as the maximum wholesale price such that \( \Pi_0^d (w) \) is decreasing on \((w_1, b)\). It must be true that \( \Pi_0^d (w_2) \geq \Pi_0^d (b) \), otherwise there exists a maximum to the right of \( b \) in which the manufacturer’s profit is larger than \( \Pi_0^d (w_2) \), which conflicts with the definition that \( w_2 \) is the highest maximum point. Define \( a = \{ w \in (w_1, b) : \Pi_0^d (w) = \Pi_0^d (w_2) \} \).

Therefore, \( \Pi_0^d (w) \) is decreasing on \((w_1, a)\) with \( \Pi_0^d (w) > \Pi_0^d (w_2) \). Moreover, \( \Pi_0^d (w) \leq \Pi_0^d (w_2) \) when \( w_2 \geq w \geq a \). Otherwise, since \( \Pi_0^d (w) \) is decreasing on \([a, b]\), there exists another maximum point within \((b, w_2)\) with manufacturer’s profit larger than \( \Pi_0^d (w_2) \). When \( \Pi_1^d (a) > r > \Pi_1^d (w_1) \), the manufacturer’s optimal delegation strategy price \( w^d (r) = \hat{w} (\gamma) \) is increasing in \( r \) and the participation constraint is
binding. The total supply chain profit under delegation strategy is increasing due to higher system effort \( e_1^d(w^d(r)) \) while the total supply chain profit under control strategy is decreasing due to lower system effort \( e_0^c(w^c(r)) \). At the same time, the Tier 1 supplier receives the same reservation profit \( r \) under control and delegation strategy. Thus, the difference of the manufacturer’s profit under delegation strategy and control strategy is also increasing. When \( \Pi_1^d(w_2) \geq r \geq \Pi_1^d(a) \), the manufacturer’s optimal delegation strategy price \( w^d(r) = w_2 \) and the manufacturer’s delegation strategy profit stays the same. Similarly, the difference of the manufacturer’s profit under the delegation strategy and control strategy is increasing. When \( r > \Pi_1^d(w_2) \), continue the previous process on \( [w_2, p] \), and it follows that the difference of the manufacturer’s profit under the delegation strategy and control strategy is increasing. Thus if \( r \leq r' \) and the delegation strategy is optimal under \( r \), it is also optimal under \( r' \), proving part (v). The results for \( a_0 \) and \( a_1 \) follow similarly, proving parts (ii) and (iv). \( \square \)

**Proof of Proposition 4.** Under substitutable effort, the system exerts all effort from the low cost stage \( (\alpha')^{-1} \left(-\min_{k_0,k_1} \right) \). It is straightforward that the effort is increasing in \( \gamma, \beta \) and \( a_i \). \( \square \)

**Proof of Proposition 5.** (i) Fixing the manufacturer’s strategy to delegation, the manufacturer’s optimization problem is

\[
\max_{c \leq w \leq p} (p - w) d - \alpha \left( e_1^d(w) \right) L_0(w) \\
\text{s.t. } (w - c) d - k_1 e_1^d(w) - \alpha \left( e_1^d(w) \right) L_1(w) \geq r
\]

The optimal system effort is \( e_1^d(w^d) = \left( \alpha' \right)^{-1} \left(-\frac{k_1}{L_1(w^d)} \right) \). Following the same logic as before, we can show that \( e_1^d(w^d) \) is increasing in \( a_0 \) and \( \beta \). When \( \gamma \) increases, \( \Pi_1^d(w) \) decreases, thus \( \hat{w} \) increases.

Under \( \alpha(x) = \beta e^{-x} \), \( \Pi_0^d(w) \) is concave in \( w \) with

\[
\frac{\partial \Pi_0^d(w)}{\partial w} = -d + \gamma d \frac{k_1 L}{L_1(w)^2}
\]

Let \( w_1(\gamma) \) denote the unconstrained optimizer of \( \Pi_0^d(w) \), which satisfies \( L_1(w_1(r))^2 = Lk_1 \gamma \). The optimal delegation price is \( w^d(\gamma) = \max \{ \hat{w}(\gamma), w_1(\gamma) \} \). From the equation, we know \( L_1(w_1(r)) \) is increasing in \( \gamma \), and \( e_1^d(w_1(r)) \) increasing in \( \gamma \). At the same time, \( \hat{w}(\gamma) \) is increasing in \( \gamma \) and \( e_1^d(\hat{w}(\gamma)) \) is increasing in \( \gamma \). Given \( \hat{w}(\gamma) \) and \( w_1(r) \) is continuous, \( e_1^d(w^d(r)) \) is also increasing in \( \gamma \). Using the same method, we can show that \( e_1^d(w^d(a_1)) \) is increasing in \( a_1 \). Note here, we ignore the case when \( \frac{\partial \Pi_0^d}{\partial w}(p) > 0 \). This is because under this case, the manufacturer’s profit function \( \Pi_0^d(w) \) is increasing over \( [c, w_1(\gamma)] \) and the manufacturer has incentive give the Tier 1 supplier wholesale price \( w \) higher than \( p \), i.e. \( w^d(\gamma) = w_1(\gamma) \geq p \). Under this situation, \( L_1(p) = \gamma (p - c) d + a_1 \) increases.

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and \( e^d_1(w^d(r)) \) still increases. In addition, this leaves the manufacturer negative optimal profit, which violates our assumption that the manufacturer should have non-zero profit.

(ii) Fixing the manufacturer’s strategy to be the control strategy, the manufacturer’s optimization problem is

\[
\max_{c \leq w \leq p} (p - w) d - k_0 e^c_0(w) - \alpha (e^c_0(w)) L_0(w) \\
\text{s.t.} \quad (w - c) d - \alpha (e^c_0(w)) L_1(w) \geq r
\]

Since the manufacturer’s profit is decreasing in \( w \), the optimal control strategy price is the minimal price \( w^c \) satisfying \( \Pi^c_1(w^c) \geq r \). The resultant effort is \( e^c_0(w^c) = \left( \alpha' \right)^{-1} \left( -\frac{k_0}{L_0(w^c)} \right) \). When \( a_0 \) increases, manufacturer’s loss function \( L_0(w) \) increases. Thus \( \Pi^c_1(w) \) is increasing and \( w^c \) is decreasing in \( a_0 \). Thus the system effort \( e^c_0(w^c) \) is increasing, because \( L_0(w^c) = \gamma (p - w^c) d + a_0 \) is increasing. Similarly, when \( a_1 \) increases, the Tier 1 supplier’s loss function \( L_1(w) \) is increasing. Thus \( \Pi^c_1(w) \) is decreasing and \( w^c \) is increasing in \( a_0 \). The system effort \( e^c_0(w^c) \) is decreasing, because \( L_0(w^c) = \gamma (p - w^c) d + a_0 \) is decreasing. Under the exponential risk function, \( e^c_0(w) = \left( \lambda' \right)^{-1} \left( -\frac{k_0}{\beta L_0(w)} \right) \). The manufacturer’s profit function is

\[
\max_{c \leq w \leq p} (p - w) d - k_0 e^c_0(w) + k_0 \\
\text{s.t.} \quad (w - c) d + \frac{k_0}{L_0(w)} L_1(w) \geq r
\]

Since \( \Pi^c_1(w) \) is independent of \( \beta \), \( w^c \) is independent of \( \beta \). The system effort \( e^c_0(w^c) \) is increasing in \( \beta \), since \( \beta L_0(w^c) \) is increasing in \( \beta \). Similar analysis applies for \( \gamma \). \( \square \)

**Proof of Proposition 6.** When \( a_0 \leq \overline{a}_0 \), the delegation strategy is optimal and \( w^* \) is increasing in \( a_0 \). Thus when \( a_0 \leq \overline{a}_0 \), the system optimal effort \( e^d_0(w^*) = \left( \alpha' \right)^{-1} \left( -\frac{k_1}{L_1(w^*)} \right) \) is increasing. When \( a_0 > \overline{a}_0 \), the control strategy is optimal. The optimal price is \( w^c \) is decreasing and the system effort \( e^c_0(w^c) = \left( \alpha' \right)^{-1} \left( -\frac{k_0}{L_0(w^c)} \right) \) is increasing. In order to prove that the optimal effort is increasing globally, we need to show that the optimal system effort is increasing even when the optimal strategy changes from delegation to control or vice versa. According to the Envelope Theorem, we have

\[
\frac{\partial \Pi^c_0(w^c)}{\partial a_0} = -\alpha \left( \left( \alpha' \right)^{-1} \left( -\frac{k_0}{\gamma (p - c) d + a_0} \right) \right) \\
\frac{\partial \Pi^c_0(w^d)}{\partial a_0} = -\alpha \left( \left( \alpha' \right)^{-1} \left( -\frac{k_1}{\gamma (w - c) d + a_1} \right) \right)
\]
Here $w^d$ is the optimal price under delegation strategy. At $\pi_0$, we have $\Pi_0^c(w^c) = \Pi_0^d(w^d)$ according to the intermediate value theorem. If the system optimal strategy changes from delegation to control, we must have
\[
\frac{\partial \Pi_0^c(w^c)}{\partial a_0} \geq \frac{\partial \Pi_0^d(w^d)}{\partial a_0}
\]
\[
\left(\alpha'\right)^{-1}\left(-\frac{k_0}{\gamma (p-w^c)(d+a_0)}\right) \geq \left(\alpha'\right)^{-1}\left(-\frac{k_1}{\gamma (w^d-c)(d+a_1)}\right)
\]
Therefore, the optimal effort increases at $\pi_0$ and increases generally in $a_0$. However, $e^*$ is not monotone in $\gamma$, $a_1$, or $\beta$, as illustrated by the counterexamples in the discussion. $\Box$

**Proof of Proposition 7.** To coordinate the supply chain, we need to incentivize the centralized optimal effort $\left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right)$ from the Tier 1 supplier when $e_0 = 0$. Since $e_1^d(w, \varphi) = \left(\alpha'\right)^{-1}\left(-\frac{k_1}{\gamma (w-c)(d+a_1+\varphi)}\right)$, we must have $\varphi = \gamma (p-w) d + a_0$. However, the Tier 1 supplier accepts contract if and only if its expected profit is greater than $r$. Since
\[
\Pi^* = (p-c) d - k_1 \left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right) - \alpha \left(\left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right)\right) L \geq r
\]
and
\[
(p-c) d - k_1 \left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right) - \alpha \left(\left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right)\right) L < r
\]
according to intermediate value theorem, there exists some $w$ so that the Tier 1 supplier’s profit exactly equals $r$. Therefore, the Tier 1 supplier accepts the contract and the coordinating contract is guaranteed to exist. Moreover, the optimal wholesale price $w$ is
\[
w^* = \frac{\alpha \left(\left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right)\right) L + k_1 \left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right) + r}{d} + c
\]
\[
= (1-\theta^*) (p-c) + c
\]
with the optimal penalty $\varphi^* = \gamma (p-w^*) d + a_0$. Furthermore, $w^*$ is increasing in $k_1$ with first order derivative $\left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right)$, and therefore $\varphi^*$ is decreasing in $k_1$. Similarly, it is straightforward to show $w^*$ is increasing in $a_0$, $a_1$ and $t$, and $\varphi^*$ is decreasing in $a_1$ and increasing in $a_0$. To see the impact of $\gamma$ on $\varphi^*$, the first order derivative is $\left(\theta^* - \gamma \left(\alpha'\right)^{-1}\left(-\frac{k_1}{L}\right)\right) (p-c) d$. Thus $\varphi^*$ is increasing when $\theta^* \geq \gamma \alpha^*$ and decreasing in $\gamma$ if $\theta^* < \gamma \alpha^*$. $\Box$

**Proof of Proposition 8.** To coordinate the supply chain, we need to incentivize the centralized optimal effort $\left(\alpha'\right)^{-1}\left(-\frac{k_0}{L}\right)$ from the manufacturer, with $e_1 = 0$. From the previous analysis, we know the manufacturer exerts zero or $e_1^d(w, \varphi) = \left(\alpha'\right)^{-1}\left(-\frac{k_0}{\gamma (p-w)(d+a_0+\varphi)}\right)$ effort. And it exerts effort
$e_0^d(w, \varphi)$ effort only if $w \geq w_s$. Therefore we must have

$$\frac{k_0}{\gamma(p - w) + a_0 - \varphi} = \frac{k_0}{L} \quad -\varphi = \gamma(w - c) + a_1$$

When $-\varphi = \gamma(w - c) + a_1$, the Tier 1 supplier encounters zero loss $L_1(w) = 0$ from non-compliance and therefore has no incentive to exert effort, i.e. $e_1 = 0$. In addition, there exists $w^* \in [c, p]$ so that the Tier 1 supplier receives reservation profit $r$,

$$(w^* - c) d = r \iff w^* = \frac{r}{c} + d$$

Given

$$(p - c) d \geq r + k_0 \left(\alpha'\right)^{-1} \left(-\frac{k_0}{L}\right) + \alpha \left(\alpha'\right)^{-1} \left(-\frac{k_0}{L}\right) L$$

and $(c - c) d < r$

At last, we need to show that $w^* > w_s$, i.e. given $\varphi^*$ and $w^*$, the manufacturer has higher profit under control strategy than that under delegation strategy. Under control strategy, manufacturer has profit $(p - c) d - r - k_0 \left(\alpha'\right)^{-1} \left(-\frac{k_0}{L}\right) - \alpha \left(\alpha'\right)^{-1} \left(-\frac{k_0}{L}\right) L$. Under delegation strategy, the manufacturer has profit $(p - c) d - \alpha(0) L$. Apparently, the manufacturer has larger profit under control strategy. Therefore, the optimal coordinating contract has $\varphi^* = -a_1 - \gamma r$ and $w^* = \frac{r}{c} + d$. \(\square\)

**Proof of Proposition 9.** Under the centralized setting, the supply chain profit is

$$(p - c) d - k_0 e_0 - k_1 e_1 - \alpha(e_0 e_1) L$$

The optimal solution could follow two cases: (1) $e_0^* = 0$, $e_1^* = 0$; (2) $e_0^* > 0$, $e_1^* > 0$. In the latter case,

$$-k_0 - \alpha'(e_0^* e_1^*) e_1^* L = 0$$

$$-k_1 - \alpha'(e_0^* e_1^*) e_0^* L = 0$$

Thus $e_0^* = \frac{k_1}{k_0} e_1^*$. The problem is equivalent to solving

$$\max_{e_0 \geq 0} \Pi(w, \varphi, e_0) = (p - c) d - 2k_0 e_0 - \alpha \left(\frac{k_0}{k_1} e_0^2\right) L$$

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When \( e_0 \to \infty \), \( \Pi(w, \varphi, e_0) \to -\infty \). There exists a threshold \( a \) such that when \( e_0 \geq a \), \( \Pi(w, \varphi, e_0) \leq \Pi(w, \varphi, 0) \). The maximizer of a continuous function over a closed set \([0, a]\) is guaranteed to exist. Hence, if \( e_0^* > 0 \), it satisfies \( \alpha' \left( \frac{k_0}{k_1} e_0^{*2} \right) = -\frac{k_1}{e_0 L} \). Define \( \Omega^+ \) to be the set of parameter values for which
\[
\left\{ \max_{e_0 > 0} -2k_0e_0 + \left( \alpha(0) - \alpha \left( \frac{k_0}{k_1} e_0^* \right) \right) L > 0 \right\}.
\]
If the system is in set \( \Omega^+ \), the optimal effort \( e_0^* > 0 \); hence, if the set \( \Omega^+ \) expands with respect to a particular parameter, then parameter values that enter the set result in “increased” effort (i.e., move from zero optimal effort to non-zero effort). Specifically, we consider the sensitivity of set \( \Omega^+ \) to the supply chain loss function \( L \). It is straightforward that when \( L \) increases, \( \Omega^+ \) expands. Moreover, consider the sensitivity of \( e_0^* \) with respect to \( L \). Taking the derivative over \( L \), we have
\[
\left( 2\alpha'' \left( \frac{k_0}{k_1} e_0^{*2} \right) \frac{k_0}{k_1} e_0^{*2} + \alpha' \left( \frac{k_0}{k_1} e_0^{*2} \right) \right) \frac{\partial e_0^*}{\partial L} = \frac{k_1}{L^2}.
\]
Based on the optimality of \( e_0^* \), we know
\[
\left. \frac{\partial^2 \Pi(w, \varphi, e_0)}{\partial^2 e_0} \right|_{e_0 = e_0^*} = -2\frac{k_0}{k_1} L \left( 2\alpha'' \left( \frac{k_0}{k_1} e_0^{*2} \right) \frac{k_0}{k_1} e_0^{*2} + \alpha' \left( \frac{k_0}{k_1} e_0^{*2} \right) \right) \bigg|_{e_0 = e_0^*} \leq 0
\]
Thus \( \frac{\partial e_0^*}{\partial L} > 0 \), i.e., \( e_0^* \) is increasing in \( L \). When the external pressure increases from the centralized supply chain (\( \gamma, \beta, a_i \) increases), \( L \) increases. Therefore, the equilibrium effort level \( \frac{k_0}{k_1} e_0^{*2} \) is increasing.

Under a decentralized supply chain with \( \alpha(x) = \beta e^{-x} \), we need to solve the manufacturer’s optimal strategy. First, given the manufacturer’s effort level \( e_0 \) and wholesale price \( w \), consider the Tier 1 supplier’s optimal effort strategy \( e_0^*(e_0, w) \). The Tier 1 supplier’s profit is \( (w - c) d - k_1 e_1 - \alpha(e_0 e_1) L_1(w) \), hence we have \( e_1^*(e_0, w) > 0 \) if and only if \( \alpha'(e_1 e_0) e_0 = -\frac{k_1}{L_1(w)} \). Since \( \alpha'(e_1 e_0) e_0 \) is increasing in \( e_1 \), this holds if and only if \( \alpha'(0) e_0 < -\frac{k_1}{L_1(w)} \), i.e., \( e_0 > e_0^*(w) = -\frac{k_1}{\beta L_1(w)} \). In this case, \( e_1^*(e_0, w) = (\frac{\alpha'}{e_0})^{-1} \left( -\frac{k_1}{L_1(w) e_0} \right) \). If \( e_0 \leq e_0^*(w) \), the optimal \( e_1^*(e_0, w) = 0 \).

Next, we consider the manufacturer’s optimal effort \( e_0^* \) given \( w \). When \( e_0 \geq e_0^* = \frac{k_1}{\beta L_1(w)} \), the manufacturer’s profit function is \( (p - w) d - k_0 e_0 - \frac{k_1}{L_1(w) e_0} L_0(w) \). Optimizing over \( e_0 \geq e_0^* \), the optimum is \( \sqrt{\frac{k_1 L_0(w)}{k_0 L_1(w)}} \) if \( L_0(w) L_1(w) > \frac{k_1 k_0}{\beta^2} \). Otherwise, it is \( e_0^* \) if \( L_0(w) L_1(w) \leq \frac{k_1 k_0}{\beta^2} \). Further, we consider the global optimum \( e_0^* \)
\[
\max \left\{ (p - w) d - \alpha(0) L_0(w), \max_{e_0 \geq e_0^*} (p - w) d - k_0 e_0 - \frac{k_1}{L_1(w) e_0} L_0(w) \right\}
\]
Thus, $e_0^* = \sqrt{\frac{k_1 L_0(w)}{k_0 L_1(w)}}$ is optimal if and only if $L_0(w) L_1(w) \geq \frac{4k_1 k_0}{\beta^2}$. Under this condition,

$$e^* = e_0^* e_1^* = \log \sqrt{\frac{\beta^2 L_0(w) L_1(w)}{k_1 k_0}}$$

Otherwise, $e_0^* = 0$ and $e^* = 0$. To verify the exact dependence over $w$, consider $L_1(w)L_0(w)$. There exists $w' = \frac{p+c-\alpha}{2\gamma}$ satisfying $L_1(w) = L_0(w)$ such that when $w < w'$, $L_1(w)L_0(w)$ is increasing; when $w \geq w'$, $L_1(w)L_0(w)$ is decreasing. Moreover, there exists $w_L \leq w' \leq w_U$ satisfying $L_1(w)L_0(w) = \frac{4k_1 k_0}{\beta^2}$ such that $e_0^* = \sqrt{\frac{k_1 L_0(w)}{k_0 L_1(w)}}$ when $w \in [w_L, w_U]$, otherwise $e_0^* = 0$.

We now consider the manufacturer’s strategy preference as a function of $a_i$, $\gamma$ and $\beta$. The manufacturer’s optimal profit under the zero effort strategy is

$$\max_{c \leq w \leq p} \Pi_0^d(w) = (p-w)d - \beta L_0(w)$$

s.t. $\Pi_1^d(w) = (w-c)d - \beta L_1(w) \geq r$

Since $\Pi_0^d(w)$ is decreasing in $w$ while $\Pi_1^d(w)$ is increasing, the optimal price $w^d$ under zero effort strategy satisfies $\Pi_1^d(w^d) = r$, $w^d = \frac{r+a_1}{(1-\gamma)d} + c$. The manufacturer’s optimal profit under non-zero effort strategy is

$$\max_{w_L \leq w \leq w_U} \Pi_0^c(w) = (p-w)d - 2\sqrt{\frac{k_1 k_0 L_0(w)}{L_1(w)}}$$

s.t. $\Pi_1^c(w) = (w-c)d + \sqrt{\frac{k_0 k_1 L_0(w)}{L_1(w)}} \left( -\log \left( \sqrt{\frac{\beta^2 L_0(w) L_1(w)}{k_1 k_0}} \right) - 1 \right) \geq r$

Since $\Pi_1^c(w)$ is increasing in $w$, there exists $\hat{w}$ so that $\Pi_1^c(w) \geq r$ when $w \geq \hat{w}$. Taking the derivative of $\Pi_0^c(w)$ over $w$, we have

$$\frac{\partial \Pi_0^c(w)}{\partial w} = -d + \gamma d \sqrt{\frac{k_1 L_0(w)}{L_1(w)}}$$

Thus $\Pi_0^c(w)$ is concave when $L_1(w) < 3L_0(w)$, i.e., $L_1(w) < \frac{3}{\beta} L$. If $L_1(w) > L_0(w)$, i.e., $w > w'$, we have

$$\sqrt{\frac{k_0 k_1 L_0(w)}{L_0(w) L_1(w)^3}} < \sqrt{\frac{\beta^2 L_0^2}{4L_1(w)^2}} < \sqrt{\beta^2} = \beta$$
Therefore, \( \frac{\partial \Phi_0^c(w)}{\partial w} < 0 \) when \( w > w' \). Further, \( \Pi_0^c(w) \) is concave with respect to \([w_L, w']\) and decreasing when \( w > w' \). Denote the unconstrained optimizer of \( \Pi_0^c(w) \) as \( w_1(a_0) \), which satisfies

\[
\gamma^2 k_0 k_1 L^2 = L_0(w) L_1(w)^3
\]

Let \( w^c \) denote the optimal price under non-zero effort strategy, thus the optimal effort is \( e^* = \log \sqrt{\frac{\beta^2 L_0(w^c) L_1(w^c)}{k_1 k_0}} \).

We illustrate the analysis for \( a_0 \). To achieve that, we need to prove the following two parts: (1) when \( a_i \) increases, the manufacturer has incentive to choose the non-zero effort strategy over the zero-effort strategy; (2) under the non-zero effort strategy, \( e^* \) is increasing in \( a_i \). For the first part and for \( a_0 \), manufacturer’s optimal profit under delegation effort strategy \( \Pi_0^d(w) \) has a derivative of \(-1\) over \( a_0 \). For \( \Pi_1^c(w) \), taking derivative over \( a_0 \), we have

\[
\frac{\partial \Pi_1^c(w)}{\partial a_0} = -\frac{1}{2} \left( \frac{k_0 L_1(w)}{k_1 L_0(w)^3} \left( \log \left( \frac{k_0 k_1}{\beta^2 L_0(w) L_1(w)} \right) - 2 \right) \right)
\]

For \( w \in [w_L, w_U] \) with \( \frac{k_0 k_1}{\beta^2 L_0(w) L_1(w)} \leq \frac{1}{4} \), \( \frac{\partial \Pi_1^c(w)}{\partial a_0} > 0 \), \( \Pi_1^c(w) \) is increasing in \( a_0 \) on \([w_L, w_U]\) with the range \([w_L, w_U]\) is expanding over \( a_0 \). Lastly, taking the derivative of \( \Pi_0^c(w) \) with respect to \( a_0 \), we have

\[
\frac{\partial \Pi_0^c(w)}{\partial a_0} = -\frac{k_0 k_1}{L_0(w) L_1(w)} > -\frac{1}{2}
\]

Thus the manufacturer’s optimal profit under the control strategy decreases slower in \( a_0 \), compared with that under delegation strategy. Therefore, for \( a_0 \leq a_0' \), if control strategy is optimal under \( a_0 \), it is also optimal under \( a_0' \). For the second part, to verify the monotonicity of \( e^* \) over \( a_i \), it is sufficient to verify that of \( L_0(w^c) L_1(w^c) \) over \( a_i \). Since \( \Pi_1^c(w) \) is increasing in \( w \), denote the minimal \( w \) that satisfies the Tier 1 supplier reservation profit constraint as \( \hat{w} (a_0) \) and \( \hat{w} (a_0) \) is decreasing in \( a_0 \). Thus the optimal price \( w^c = \max \{ \hat{w} (a_0), w_1(a_0) \} \). When \( w^c = w_1(a_0) \), if \( w_1(a_0) \) increases, \( L_0(w^c) L_1(w^c) \) increases given that \( w_1(a_0) < w^c(a_0) \). If \( w_1(a_0) \) decreases, then \( L_1(w_1(a_0)) \) decreases. Therefore, \( L_0(w^c) L_1(w^c) \) must increase since the left hand side of the equation is increasing. When \( \hat{w} (a_0) \geq w_1(a_0) \), \( w^c = \hat{w} (a_0) \). Since \( \hat{w} (a_0) \) is decreasing in \( a_0 \), \( L_0(w^c) L_1(w^c) \) increases. Thus \( e^* \) is increasing. The analysis applies similarly for \( a_1, \gamma, \) and \( \beta \). □